Davidson Environmental Limited

Horoirangi Marine Reserve, North Nelson, report on rocky shore biological monitoring: 2006-2013

Research, survey and monitoring report number 694

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Rippled sand and low lying bedrock outcrop habitat from the southern reserve (Photo Rob Davidson).

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Contents

Abstract

1. Horoirangi Marine Reserve was established on 26th January 2006. In 2006, a biological baseline study for the reserve and adjacent controls was conducted.
2. The present report updates biological quantitative data for reef fish (blue cod: *Parapercis colias*, blue moki: *Latridopsis ciliaris*, and tarakihi: *Nemadactylus macropterus*), lobsters (*Jasus edwardsii*) and black foot paua (*Haliotis iris*) from rocky shores within and outside the reserve from March 2006 to March 2013.
3. In 2006, edible species of reef fish were relatively uncommon in both the reserve and control sites. In 2006, no legal sized blue cod were recorded from diver collected reserve transects.
4. Overtime, the abundance of legal sized blue cod increased in the reserve compared to control sites. Significantly more large cod were recorded from the reserve in 2008 and again in 2010 onwards compared to the control treatment.
5. The abundance of reserve sublegal cod also increased over the duration of the study, but this increase also occurred at control sites.
6. In 2013 only 2 of the 116 cod, or 1.7%, of the individuals recorded at the control sites were 30 cm or greater in length. In comparison 62 of the 169 blue cod measured (35%) in the reserve were 30 cm and above.
7. The abundance and size of blue moki and tarakihi varied throughout the study. No changes that could be attributed to reservation were documented for these fish species.
8. Lobster abundance changed due to reservation. Legal sized lobsters were more abundant in the reserve compared to control sites from 2007 onwards. At the end of the study, 3.5 times more lobsters were counted in the reserve compared to control sites.
9. The mean size of lobsters initially increased in the reserve; however, recruitment by small individuals into the reserve lowered the mean size down to control average length.
10. Very large males and females lobsters were regularly recorded in the reserve at the end of the study.
11. Paua were sampled on two occasions. Unexpectedly, mean size declined in the reserve and increased in the control sites.
12. Data collected from the first seven years of reservation suggest that blue cod and lobsters have responded to reservation.

1.0 Introduction

On 26 January 2006, the Horoirangi Marine Reserve was established. At the time of establishment, baseline surveys were conducted within the reserve and from adjacent control sites. The data collected included:

- shore profiles and video;
- key benthic invertebrate density and size;
- macroalgae percentage cover estimates;
- reef fish densities and size estimates of selected species; and
- rock lobster density, size and sex.

Since 2006, an annual monitoring programme has been undertaken, with data for reef fish and lobsters collected. Reef fish and lobsters have often been the focus of study for fisheries-related research as well as marine reserve studies in New Zealand and internationally (Mace and Johnson 1983, Buxton and Smale 1989; Cole and Creese 1990; Cole *et al.,* 1992; MacDiarmid and Breen 1993; Cole 1994; Blackwell 1997, 1998; Bennett and Attwood 1991, 1993; MacDiarmid 1993; Carbines 1998, 1999; Edgar and Barrett 1999; Cole *et al.*, 2000; Kelly 1999, 2000, 2001; Willis 2000; Willis *et al.*, 2000; Davidson 2001; Davidson *et al.*, 2002, 2005; Cole *et al.* 2002; Denny *et al.*, 2004; Freeman 2005; Shears *et al.*, 2006; Pande *et al.*, 2008; Freeman and MacDiarmid 2009, Guisado *et al.,* 2012; Freeman *et al.*, 2012). In 2013, paua data were collected for the first time since the baseline was established.

The present report updates biological quantitative data originally presented in the baseline biological report (see Davidson 2006) for:

- fish (blue cod: *Parapercis colias*, blue moki: *Latridopsis ciliaris*, and tarakihi: *Nemadactylus macropterus*);
- spiny rock lobsters (*Jasus edwardsii*; hereafter referred to as lobsters); and
- black foot paua (*Haliotis iris*; hereafter referred to as paua).

This updated report incorporates: (i) annual survey data of the density and size structure of fish populations from 2006 to 2013; (ii) annual survey data of density and size structure of lobster populations from 2006 to 2013; and (iii) density and size estimates of paua in 2006 and again in 2013.

2.0 Study area

Horoirangi MR is located along a rocky coastline situated 11 km north of Nelson City, and immediately north of the small settlement of Glenduan (Plate 1). The reserve is 904 hectares in size and encompasses approximately 5 km of relatively straight coastline (Figure 1). It is contiguous with the Nelson Boulder Bank, which extends southwest of the reserve towards Nelson City (Davey *et al.* 2005). To the northeast of the reserve are Cable Bay, Pepin Island, and Delaware Bay (located on the northeastern side of Pepin Island). Part of the area extending from the marine reserve boundary into Cable Bay is encompassed in the Wakapuaka Taipure. Control sites adjacent to the marine reserve were established on the Boulder Bank, in Cable Bay, around Pepin Island and in Delaware Bay.

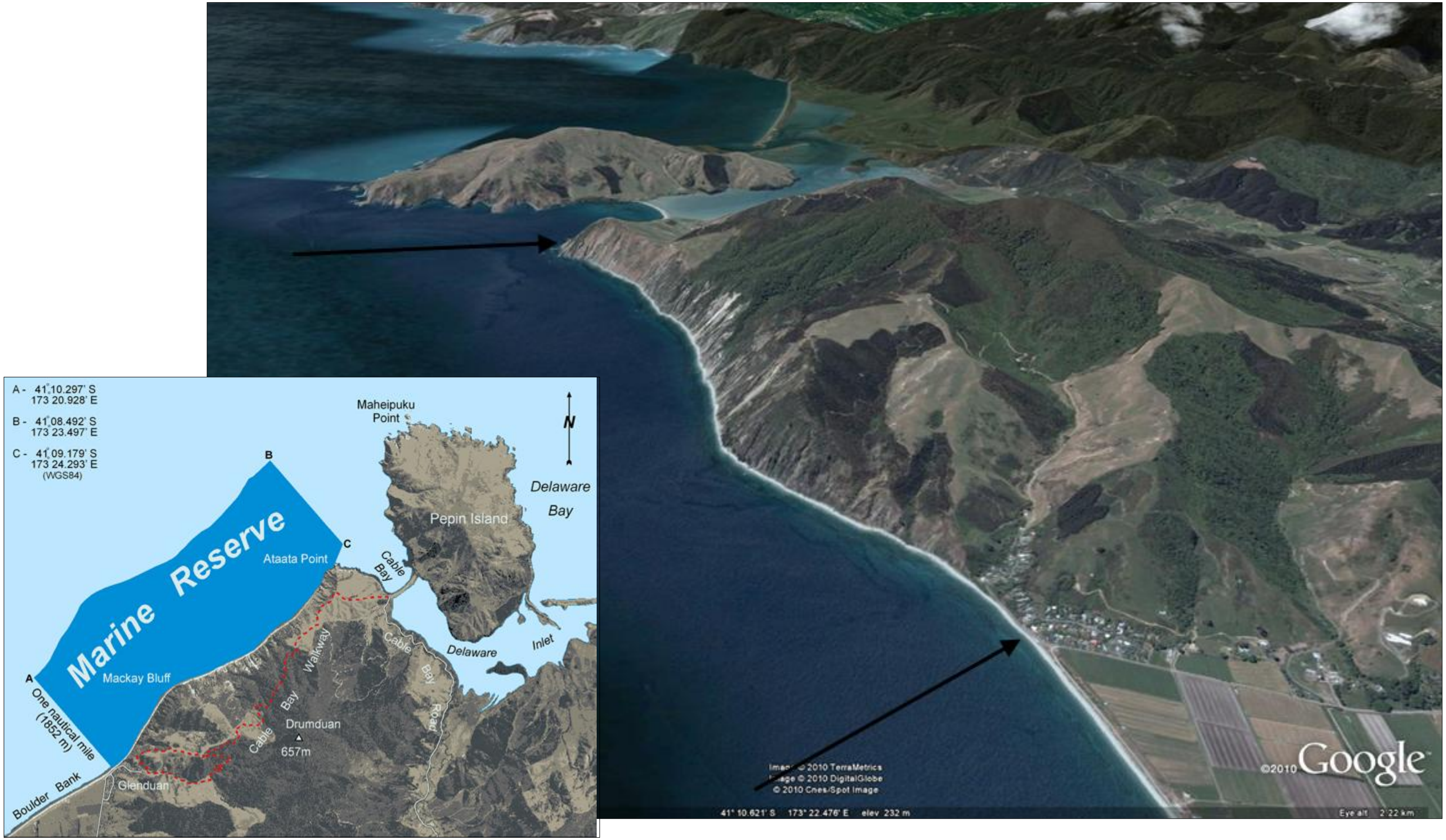


Plate 1. Glenduan (foreground) to Delaware Bay (distant) coastline with north-east and south-west reserve boundaries indicated.

3.0 Methods

3.1 Fish

Between January and March each year, the abundance of all reef fish species and the size of target fish species was assessed using established underwater visual transect methods (see Bell 1983; McCormick and Choat 1987; Buxton and Smale 1989; Cole *et al.,* 1990; Cole 1994; Willis *et al,.* 2000, Davidson 2001).

In 2006, twelve replicate 2 x 30 m (w x l) fish transects were sampled from each of six reserve and six control sites. From 2007, the number of sample sites was increased to eight reserve and eight control sites (Table 1, Figures 1a and 1b). All transects were established parallel to shore in boulder and reef habitat between 5 to 10 m depth, adjusted to mean low water.

At each site, a lead weight at the start of the transect line was dropped onto the substrate within the designated depth range. The line was automatically reeled off a spool as the diver holding the spool swam away from the lead weight. At a distance of 5 m from the weight (as indicated by a marker on the line), the diver started counting fish within an estimated 2 x 2 x 30 m (w x h x l) "tunnel". Triplefins and crevice dwelling species were not included in diver counts, however, all other fish were identified to species level and counted. Transects were swum at a constant slow speed, but fast enough to ensure that swimming blue cod did not overtake the divers. Underwater visibility was ≥ 4 m horizontal distance for all fish counts. During the collection of fish density data, divers recorded the estimated size of blue cod, blue moki, tarakihi, snapper and butterfish. These species were sized both within and outside transects in order to increase sample size. It should be noted that density estimates for these species differs from sample sizes for size data. To reduce observer bias, the same two trained divers collected all fish count and size data in all years.

3.2 Lobsters

From 2006, the sex and density of lobsters was sampled annually between January and April at six marine reserve sites and six control sites adjacent to the marine reserve (Table 1, Figures 2a and 2b).

The adopted sampling methodology reflected survey methodologies used elsewhere in marine reserve studies in New Zealand (e.g., Freeman *et al.,* 2012). At each site, ten 100 m^2 lobster transects (4 x 25 m) were sampled between 6 and 14 m depth (depending on the benthic topography at each site), with transects evenly distributed between shallow and deep strata within the range of depths available. Lobster transects were haphazardly placed within these strata so that transects commenced on habitat suitable for lobsters (i.e., not sand or flat bedrock). On occasion, habitat type changed along transects. In such instances, divers altered course to avoid sand or unsuitable habitat; however, this was not always possible and some transects included habitats not utilized by lobsters. This tended to happen at and two of the reserve sites where lobster habitat was patchily distributed.

On each transect, divers searched all crevices, caves and cracks within each transect using a dive torch and recorded the sex and size (as carapace length CL, in 5 mm intervals) of lobsters encountered. Rulers were used to estimate and, when possible, measure lobster size.

A core group of three divers was involved in all surveys. The size and sex of some lobsters could not be measured because they were concealed beneath boulders or within caves. As a result, lobster density and sample size for size data do not correspond (i.e., all lobsters are included in density calculations, but lobsters that could not be sexed or measured do not appear under the male, female or juvenile categories). Underwater visibility was > 2 m horizontal distance during all counts.

3.3 Black foot paua

From 2006, the density and size (maximum length) of paua was sampled from six marine reserve sites and six control sites adjacent to the marine reserve. In 2006, the density of paua was sampled in ten 1 x 1 m quadrats haphazardly deployed from 0-0.5 m depth below mean low water at each site. In 2013, sample size was increased to a minimum of 30 quadrats per site sampled between 0-2 m depth.

At each site, a minimum of 50 paua were measured from the same depth zone where density data were collected (apart from two sites where paua were either absent or uncommon (2006: RB1 n = 25, CB5 n = 36; 2013: CB2 n = 27, CB3 n = 0)).Divers were instructed to measure all paua encountered. If paua were abundant, divers moved a minimum of 6 m distance before measuring another 15 paua. Where paua were uncommon all paua encountered were measured. The aim of this methodology was to collect a representation of the size structure at each site. Paua size was measured to the nearest millimeter *in situ* by divers using calipers.

3.4 Statistical analyses

All statistical analyses of fish, lobster and paua size and density data were conducted using Sigmaplot 12.1.0.15. Individual tests were done for each species (and where appropriate size class (e.g., small and large blue cod) in each year of sampling. Species data were often pooled from all sites sampled within each treatment.

On most occasions the t-test normality test of raw data failed. A Mann-Whitney Rank Sum test was then used to compare data sets. A significance level of 0.05 was used for all tests.

Table 1. Lobster, fish and paua sample sites from Horoirangi Marine Reserve and control sites. Note: fish sites RF7, RF8, CF7, and CF8 were added in 2007 and sampled every year thereafter.

Type	No. & Depth (m)	Coordinates
Lobster transect	CL1	41 06.71852,173 30.46279
Lobster transect	CL2	41 08.29355,173 25.72865
Lobster transect	CL3	41 08.18976,173 25.47934
Lobster transect	CL4	41 08.43218,173 24.69114
Lobster transect	CL5	41 09.33501,173 24.42510
Lobster transect	CL6	41 11.01073,173 21.63083
Lobster transect	RL1	41 09.35008,173 24.13766
Lobster transect	RL2	41 09.83079,173 23.55336
Lobster transect	RL3	41 10.19100,173 22.76100
Lobster transect	RL4	41 10.33473,173 22.25068
Lobster transect	RL5	41 10.53994,173 22.09955
Lobster transect	RL6	41 10.74305,173 21.93164
Fish transect	CF1	41 06.69813,173 30.45541
Fish transect	CF2	41 08.18976,173 25.47934
Fish transect	CF3	41 08.43218,173 24.69114
Fish transect	CF4	41 09.33501,173 24.42510
Fish transect	CF5	41 11.00987,173 21.63140
Fish transect	CF6	41 11.37377,173 20.83302
Fish transect	CF7	41 07.85493,173 30.35333
Fish transect	CF8	41 08.66010,173 24.76299
Fish transect	RF1	41 09.34647,173 24.14851
Fish transect	RF2	41 09.82928,173 23.55442
Fish transect	RF3	41 10.12646,173 23.01525
Fish transect	RF4	41 10.38036,173 22.31374
Fish transect	RF5	41 10.64227,173 22.04282
Fish transect	RF6	41 10.78475,173 21.88724
Fish transect	RF7	41 09.62159,173 23.81672
Fish transect	RF8	41 10.24730,173 22.62499
Blackfoot paua	CB1	41 08.27828,173 25.70457
Blackfoot paua	CB2	41 08.69559,173 24.78416
Blackfoot paua	CB3	41 09.09134,173 24.84278
Blackfoot paua	CB4	41 09.36580,173 24.36631
Blackfoot paua	CB5	41 11.07200,173 21.64200
Blackfoot paua	CB6	41 11.38400,173 20.94600
Blackfoot paua	RB1	41 09.38778,173 24.09799
Blackfoot paua	RB2	41 09.62300,173 23.89000
Blackfoot paua	RB3	41 09.99508,173 23.35014
Blackfoot paua	RB4	41 10.18600,173 22.85400
Blackfoot paua	RB5	41 10.34800,173 22.40000
Blackfoot paua	RB6	41 10.94900,173 21.86500

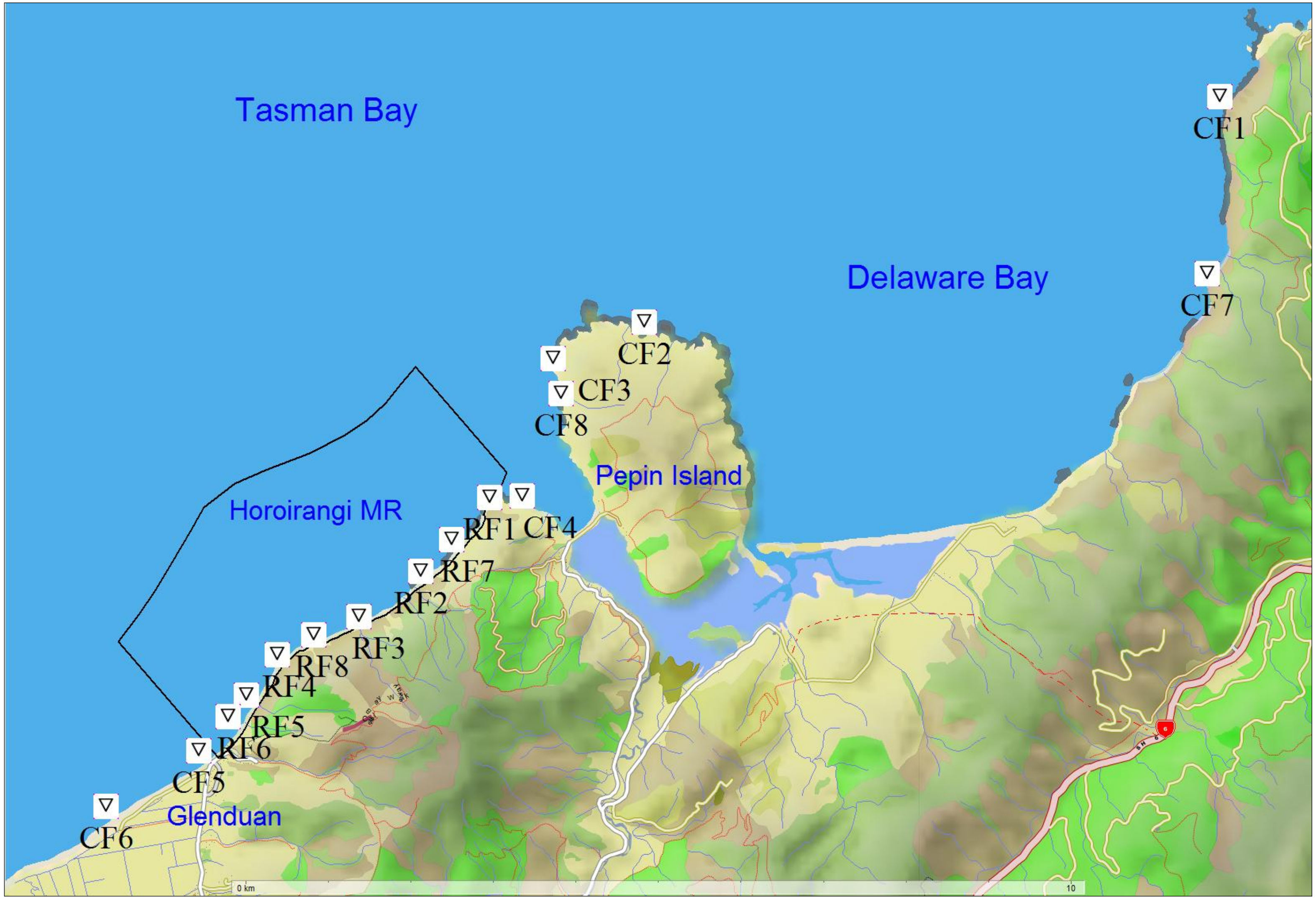


Figure 1. Location of fish sample sites in Horoirangi Marine Reserve and control sites adjacent to the reserve (RF = reserve fish, CF = control fish).

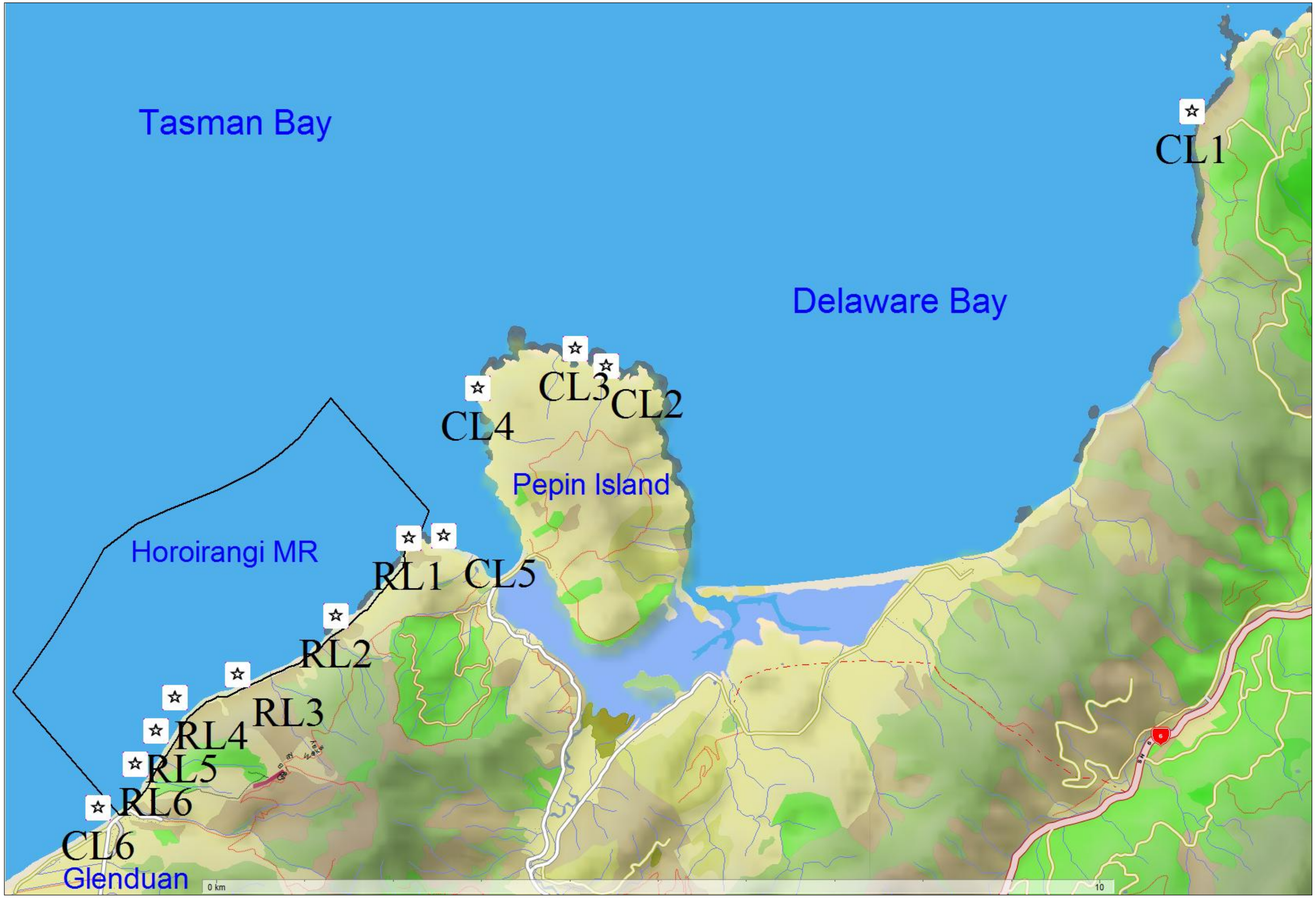


Figure 2. Location of lobster sample sites in Horoirangi Marine Reserve and control sites adjacent to the reserve (RL = reserve lobster, CL = control lobster).

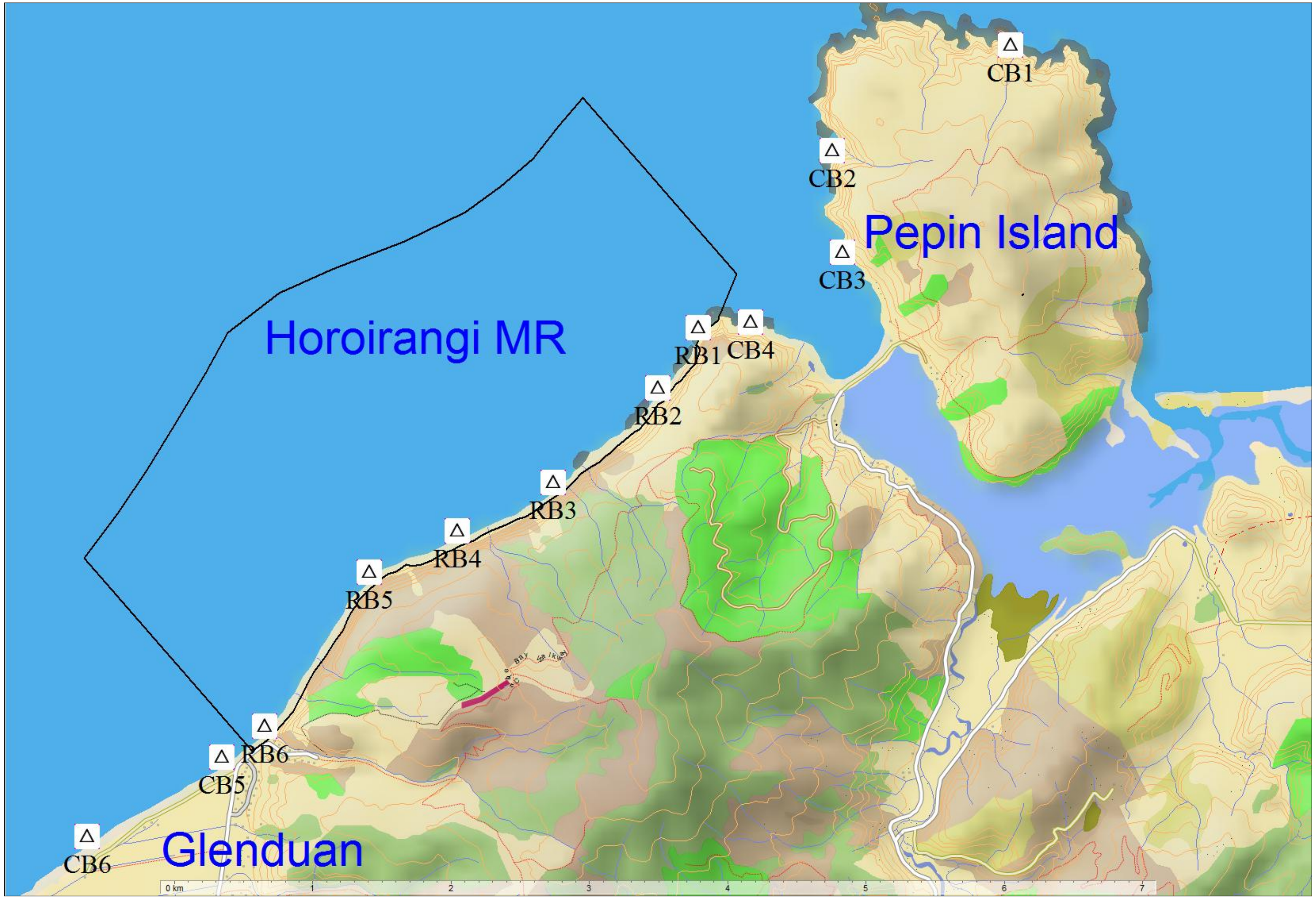


Figure 3. Location of paua sample sites in Horoirangi Marine Reserve and control sites adjacent to the reserve (RB = reserve paua, CB = control paua).

4.0 Results

4.1 Fish (diver observations)

Spotty (*Notolabrus celidotus*) were the most often encountered reef fish at both reserve and control sites throughout the study (Table 2). In 2013, divers observed blue cod more often in the reserve compared to control sites.

Divers regularly observed small snapper (*Chrysophrus auratus*) (18-26 cm length) in 2009 and 2010. These small fish were seldom seen in all other years. In 2009 and 2010, snapper were usually observed following divers, but these fish were also occasionally recorded on transects. Larger size classes of tarakihi were more often seen by divers outside the reserve at the Pepin Island control sites. Small schools of juvenile tarakihi were regularly observed both inside and outside the reserve. Goatfish (*Upeneichthys lineatus*) were seen often, but in low numbers at both reserve and control sites over the duration of the study. Butterfish (*Odax* pullus) were observed in both treatments but were very rare in all years and appeared to try and avoid divers.

Kingfish (*Seriola lalandi*) were intermittently seen by divers, usually in groups of 4-10 individuals, but sometimes up to 50 individuals were observed. Magpie perch (*Chirodactylus nigripes*), a relatively recent arrival from Australia, were relatively rare and usually seen as adults and as individual fish.

Blue cod was the only species that divers ranked as being observed more often or in higher numbers in the reserve, while most fish were observed in comparable numbers between treatments (Table 2). Tarakihi were more abundant and observed more often at control than at reserve sites.

Table 2. Overall relative abundance of reef fish for the reserve and control treatments (excluding triplefins) assessed bydivers. Relative abundance was assigned for 2013: 1 = rare (1-2 individuals seen per dive), 2 = occasional (3-5 individuals seen per dive), 3 = common (6-10 individuals seen per dive), 4 abundant (11+ individuals seen per dive or present in schools).

Species name	Common name	Reserve	Control
Caesioperca lepidoptera	Butterfly perch	2	2
Upeneichthys lineatus	Goatfish	3	3
Helicolenus papillosus	Sea perch	1	1
Scorpis lineolatus	Sweep	2	2
Aplodactylus arctidens	Marblefish	2	2
Nemadactylus macropterus	Tarakihi	2	3
Cheilodactylus spectabilis	Red moki	1	1
Cheilodactylus nigripes	Magpie moki	1	1
Latridopsis ciliaris	Blue moki	3	2
Latridopsis aerosa	Copper moki	1	1
Notolabrus celidotus	Spotty	4	4
Notolabrus fucicola	Banded wrasse	2	2
Pseudolabrus miles	Scarlet wrasse	2	2
Parapercis colias	Blue cod	3	1
Parika scaber	Leatherjacket	1	1
Odax pullus	Butterfish	1	1
Latris lineata	Trumpeter	1	1
Seriola lalandi	Kingfish	1	1
Chrysophrus auratus	Snapper	1	1
Hippocampus abdominalis	Seahorse	1	1
Total number of species		**21**	**21**

4.2 Fish density

Density and size data were collected for 21 species of reef fish from within the reserve and adjacent control sites; however, this report focuses on the abundance and size structure of blue cod, blue moki and tarakihi. Blue cod were classified as being large (≥30cm total length) or small (<30cm total length) based on legal size limits specified in the recreational fisheries regulations for this region. No other fish species were separated into size classes.

In 2006, blue cod at both reserve and control sites were rare. No large blue cod were recorded at reserve sites, and at both reserve and control sites small blue cod were only present in very low densities (Figure 4).

The abundance of small blue cod increased from 2007 at both reserve and control sites, peaking in 2012 at control sites, well above reserve densities in the same year (Figure 4). The density of small cod in reserve sites continued to increase, peaking at the end of the study following a dip in February 2012 (Figure 4). No significant difference in the abundance of small cod were recorded between pooled reserve and control treatments over the first six years ($P > 0.124$); however, significantly more small cod were recorded from the control treatment compared to the reserve group in 2012 ($P < 0.001$). This difference was augmented due to a drop in small cod in the reserve in 2012. In 2013, the abundance of small cod declined at the control treatment and increased at the reserve treatment leaving the mean values at almost identical levels (Figure 4). The density of small blue cod at reserve sites peaked in 2013.

The abundance of large sized blue cod (>30cm) at control sites remained low throughout the study, with no large individuals being observed in 2008 and 2013 (Figure 4). In contrast, the density of large blue cod at reserve sites increased over the duration of the study, peaking in 2013 (Figure 4). With the exception of 2009, significantly more large blue cod were recorded at reserve sites than control sites from 2008 to 2013 ($P < 0.045$ in all years except 2009).

No blue moki were recorded from reserve transects in 2006. The number of blue moki observed from the control treatment was also low, however, one small school of 11 individuals was recorded from one control transect in 2006. After 2006, the abundance of blue moki increased at both reserve and control sites; however, since 2010 the abundance of blue moki has steadily declined in the reserve, but remained above 2006 and 2007 levels (Figure 5). Apart from February 2013, no significant difference in the abundance of blue moki was recorded between reserve and control treatments ($P > 0.05$) (Figure 5). In 2013, the density of blue moki at control sites was high relative to reserve sites, which continued a declining trend ($P = 0.45$).

Tarakihi densities were often variable between sites and years, especially at the control treatment where the highest peaks in density were recorded (Figure 5). Peaks in their abundance and within and between site variability were due to schools of tarakihi along transects. In some years, the abundance of tarakihi was significantly higher in the reserve (2006, 2008), however, in most years they were significantly more abundant in the control treatment (2007, 2009, 2012). In 2009 ($P = 0.05$), 2010 ($P = 0.89$), 2011 ($P = 0.5$) and 2013 ($P = 0.08$), there was no significant difference between treatments. Overall, the abundance of tarakihi ended where it started for both treatments with considerable variation occurring between years and sites (Figure 5).

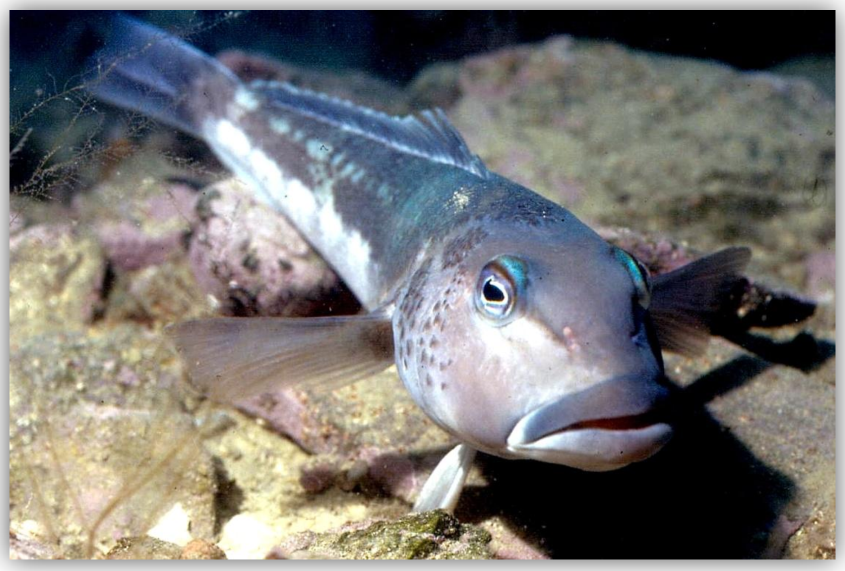


Plate 1. Adult blue cod showing bright green-blue saddle behind the head (Photo: Rob Davidson).

Plate 2. Small school of juvenile tarakihi (6-12 cm) at Mackays Bluff (Photo: Rob Davidson).

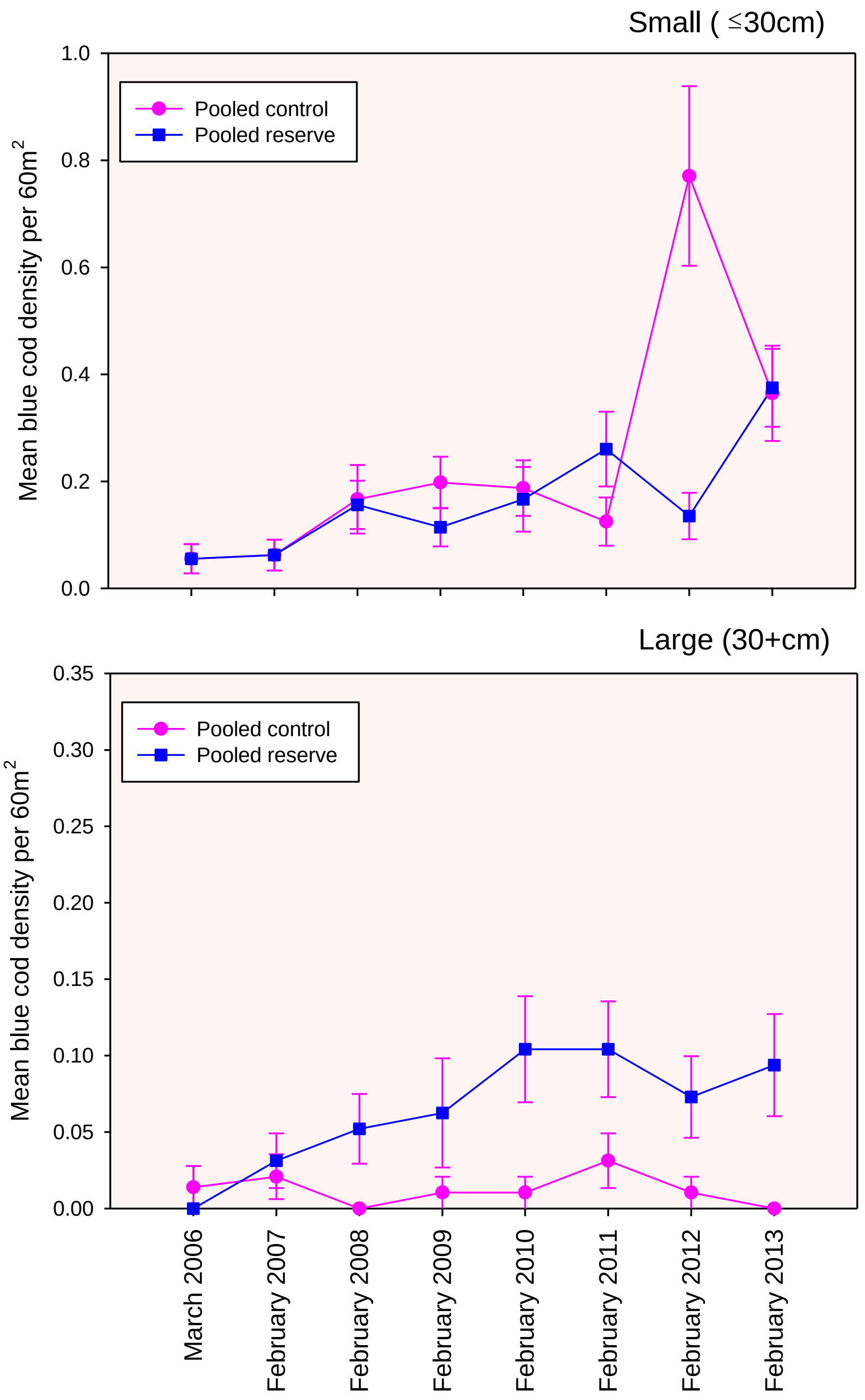
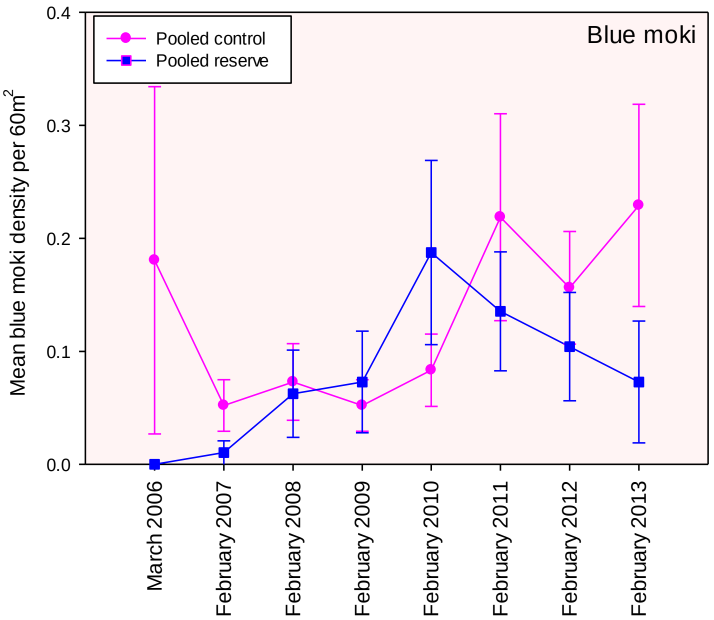


Figure 4. ***Mean density of small (top) and large (bottom) blue cod within Horoirangi reserve (blue squares) and at adjacent control sites (pink circles). Reserve start date is January 2006. Error bars are +/- 1 s.e.***



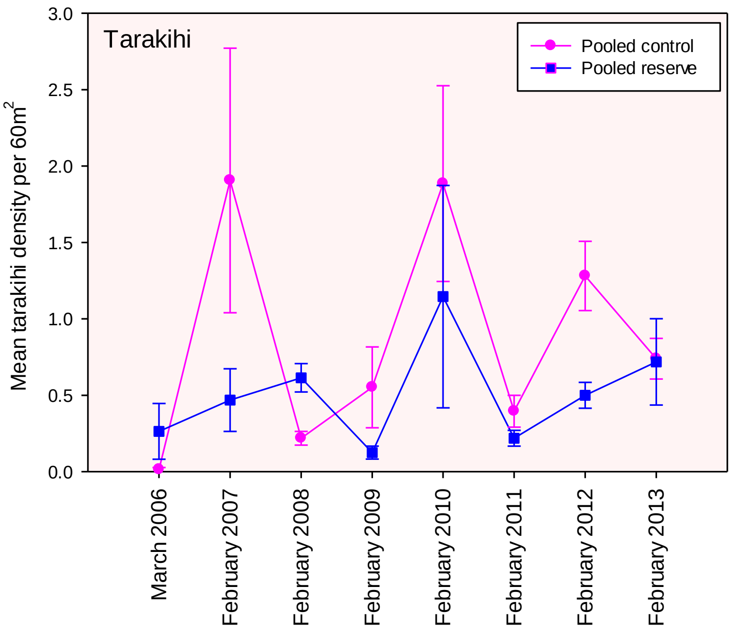


Figure 5. ***Mean density of blue moki (top) and tarakihi (bottom) within Horoirangi reserve (blue squares) and at adjacent control sites (pink circles). Reserve start date is January 2006. Error bars are +/- 1 s.e.***

4.3 Mean fish size

Relative to the control sites, the mean length of blue cod at reserve sites has remained relatively stable for the duration of the monitoring programme (Figure 6). The mean length of blue cod at reserve sites peaked in 2010, followed by a decline in 2011 and then a steady increase from 2011 to 2013 to a mean size of 27.62 cm. In the control treatment, the mean size of blue cod started above the reserve mean size, but declined to 20.75 cm in 2008. Since 2006, the mean size of blue cod in the control treatment has remained well below the reserve, and fluctuates between 20.7 and 23.5 cm.

The mean size of blue moki in reserve and control treatments followed comparable patterns throughout the study (Figure 6). Mean size started at relatively high levels in 2006 and 2007, followed by a steady decline to a low in 2010 (20.8 cm control, and 22.8 cm reserve). Since 2010 their mean size at both treatments has increased, but has not reached sizes recorded at the start of the study.

The mean size of tarakihi in 2006 and 2007 did not differ between reserve and control sites (Figure 6). Since 2007, the mean size of tarakihi in control sites has been larger than in reserve sites (with the exception of 2012 where mean size did not differ between control and reserve sites). Over the duration of the study, the mean size of tarakihi at reserve sites has fluctuated less than at control sites (Figure 6). Tarakihi were commonly present in distinct size classes at all sites. Small tarakihi between 6-12 cm length were often observed in small groups feeding on the surface of boulders and bedrock (Plate 2). A second size class was recorded with most individuals being between 17-28 cm. These larger fish were encountered more often and in higher numbers at control sites than reserve sites where the small size class usually dominated.

4.4 Blue cod size-frequency

In 2006, small sized individuals dominated blue cod population structure at both reserve and control sites. No large blue cod were counted in reserve transects, while only one was counted from control transects. Further, very few large cod were observed by divers from areas outside fish transects. This situation persisted at the control sites over the duration of the study (Figures 7a and 7b). In contrast, the number and size of large blue cod at reserve sites increased between 2006 and 2013 (Figures 7a and 7b). By 2011, the largest blue cod recorded at a reserve site was 44 cm total length (TL), compared to 34 cm TL for the largest blue cod recorded at a control site. In 2013, only 2 of the 116 (1.7%) blue cod measured at control sites, met legal size limits specified in the recreational fisheries regulations for this region. Conversely, 62 of the 169 (35%) blue cod measured at reserve sites met legal size limits (Figure 7b).

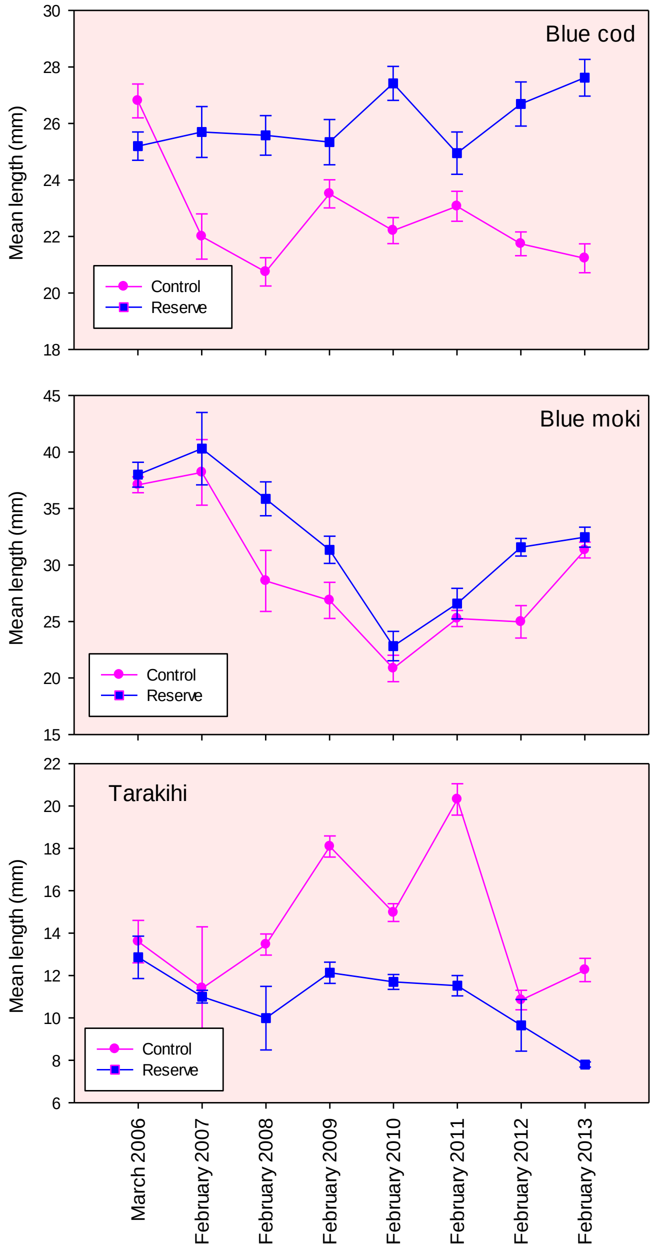


Figure 6. ***Mean size of blue cod, blue moki and tarakihi within Horoirangi reserve (blue squares) and at adjacent control sites (pink circles). Reserve start date is January 2006. Error bars are +/- 1 s.e.***

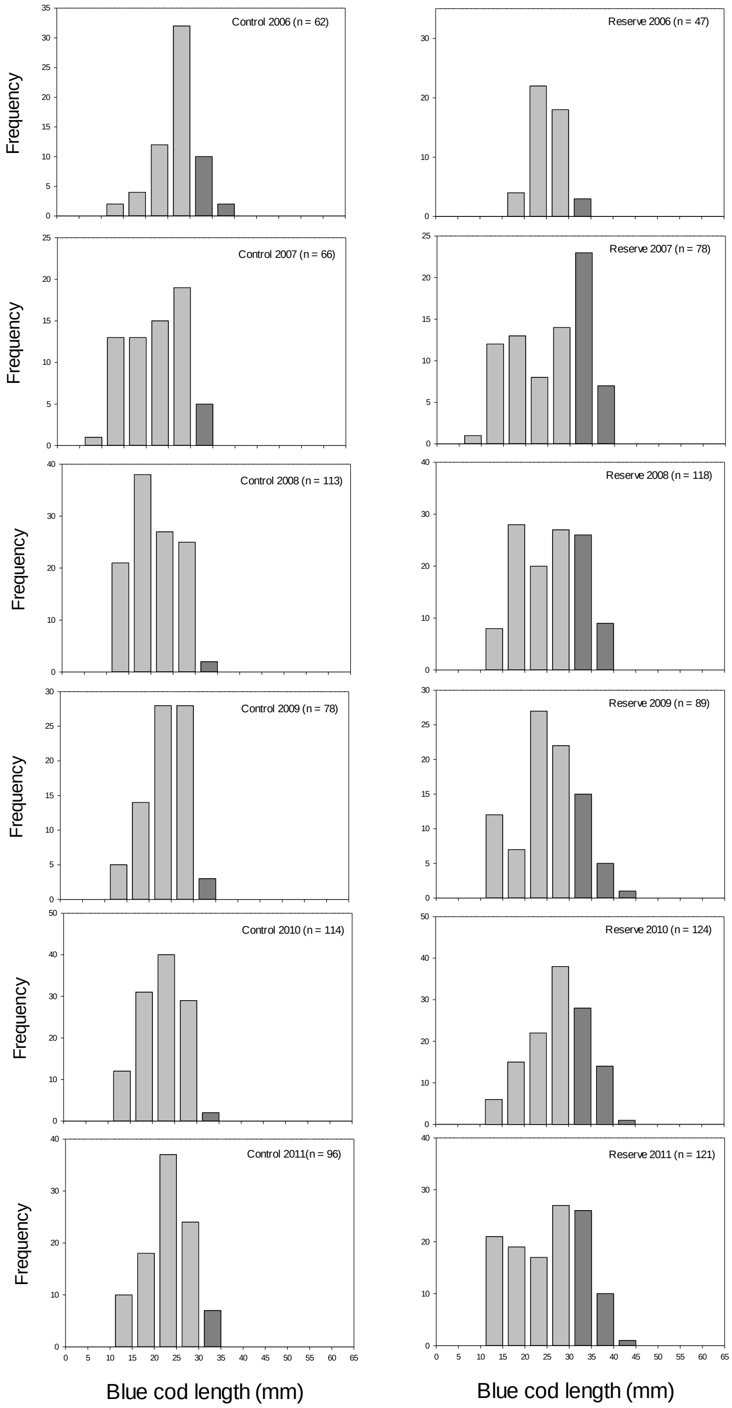


Figure 7a. Size-frequency of blue cod from pooled control and reserve sites (2006 – 2011). Light grey and dark gray bars represent large (≥30cm total length) and small (<30cm total length) blue cod based on legal size limits specified in the recreational fisheries regulations for this region, respectively.

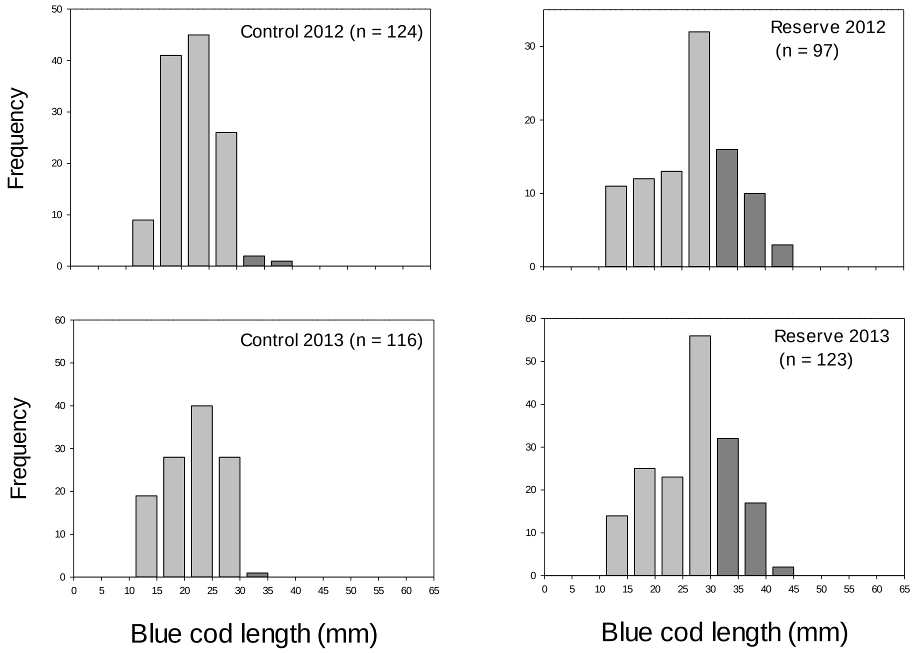


Figure 7b. Size-frequency of blue cod from control and reserve sites (2012 – 2013). Light grey and dark gray bars represent large (≥30cm total length) and small (<30cm total length) blue cod based on legal size limits specified in the recreational fisheries regulations for this region, respectively.

4.5 Blue cod abundance at individual sites

The number of blue cod recorded from fish transects at each of the reserve and control sites varied throughout the study (Figures 8, 9 and 10, Appendix 1). The "all cod" and "small cod" (<30 cm) graphs were comparable because the blue cod population was dominated by small sized individuals (Figures 8 and 9). Particular reserve and control sites consistently supported relatively few or no blue cod. Between 0-3 blue cod were consistently recorded at reserve sites RF1, RF4, RF5 and RF6. Similarly, either 0 or 1 blue cod were recorded on each sampling occasion at control sites CF4, CF6, and CF7 (Appendix 1). Conversely, higher numbers of blue cod were consistently recorded at particular reserve and control sites. Between 0 and 15 cod per were recorded sample event at reserve sites RF2, RF3, and RF7, and between 0 and 42 blue cod were recorded per sample event control sites CF1, CF3, CF5 and CF8.

For large blue cod (≥30 cm TL), between 0 and 4 individuals were counted for the combined 12 transects sampled at each site (Figure 10, Appendix 1). No large blue cod were recorded at most control sites. At reserve sites, 0 or 1 large blue cod were most regularly recorded from sites during the first three years; however, after 2009 large blue cod were more regularly recorded, with 1-4 cod often being recorded at each site (Figure 10). The density of large cod was always less than the density of small cod at all sites.

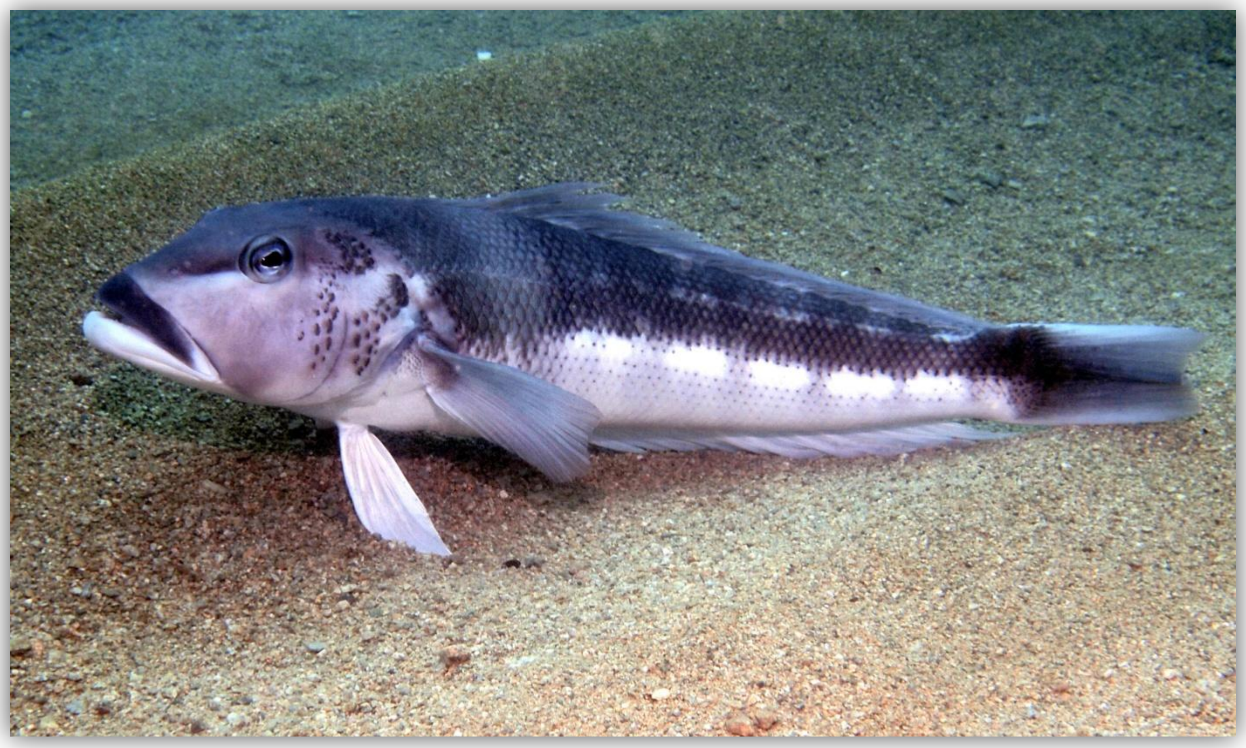
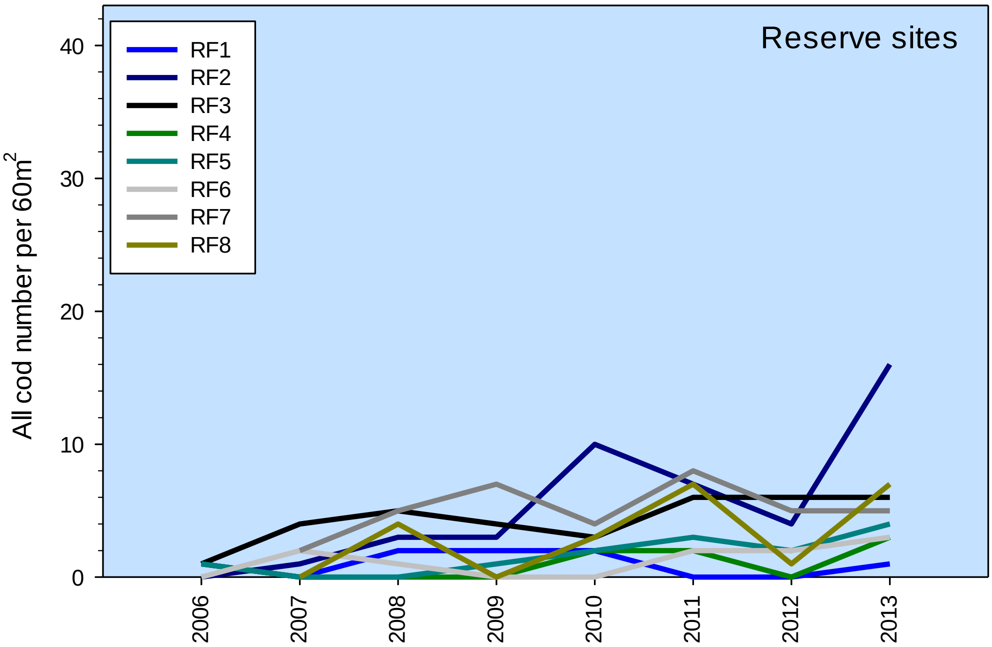


Plate 3. Adult blue cod recorded from Horoirangi MR in February 2012 (Photo: Rob Davidson).



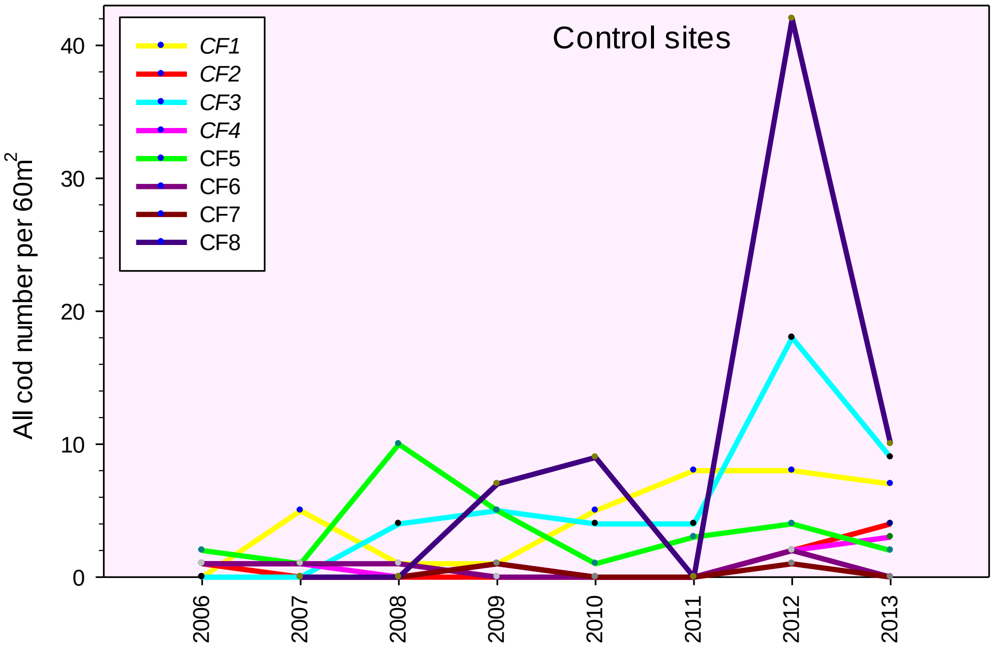
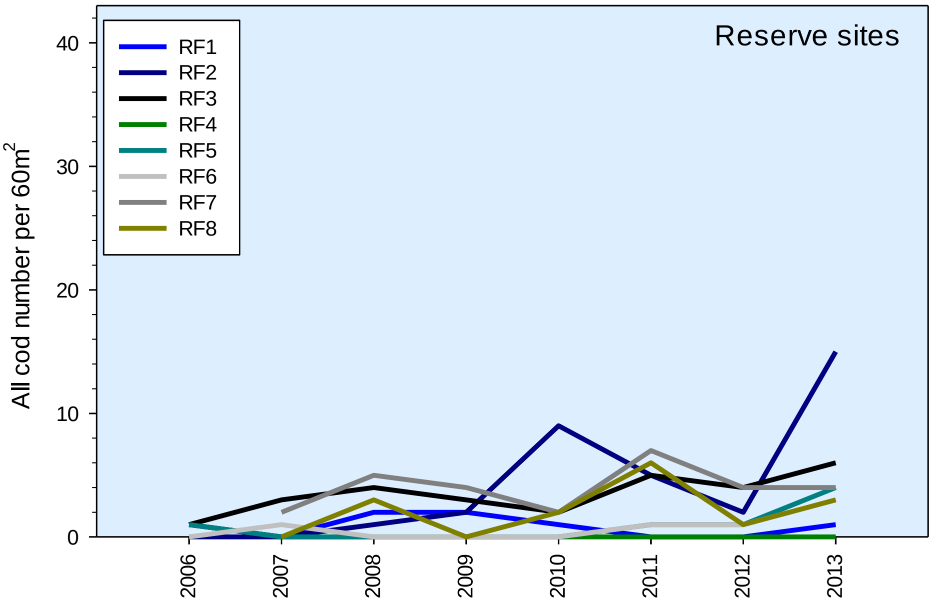


Figure 8. Total number of blue cod pooled across replicate transects (n = 6 in 2006 and 8 in 2007-13) at each site from 2006 to 2013.



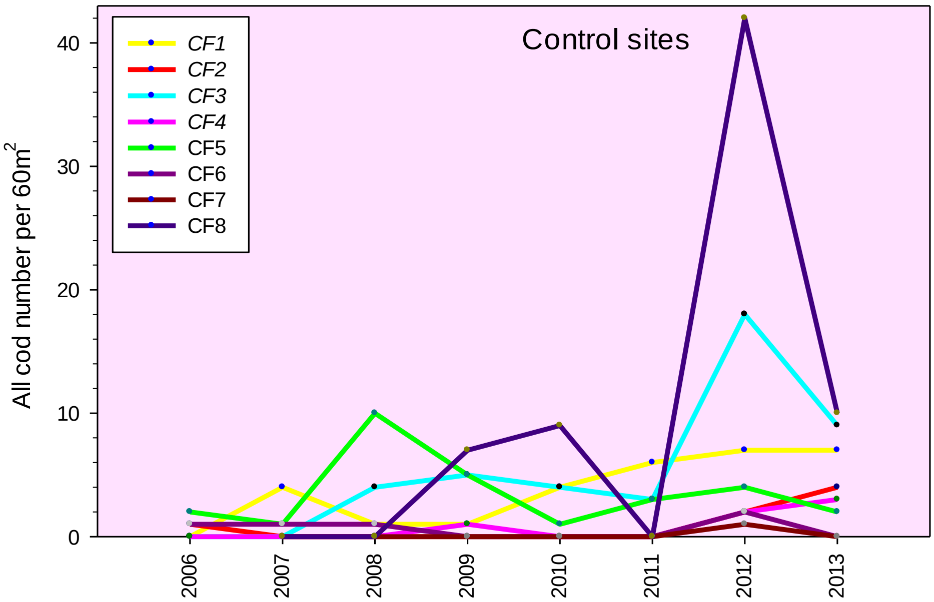


Figure 9. ***Total number of small blue cod pooled across replicate transects (n = 6 in 2006 and 8 in 2007-13) at each site from 2006 to 2013.***

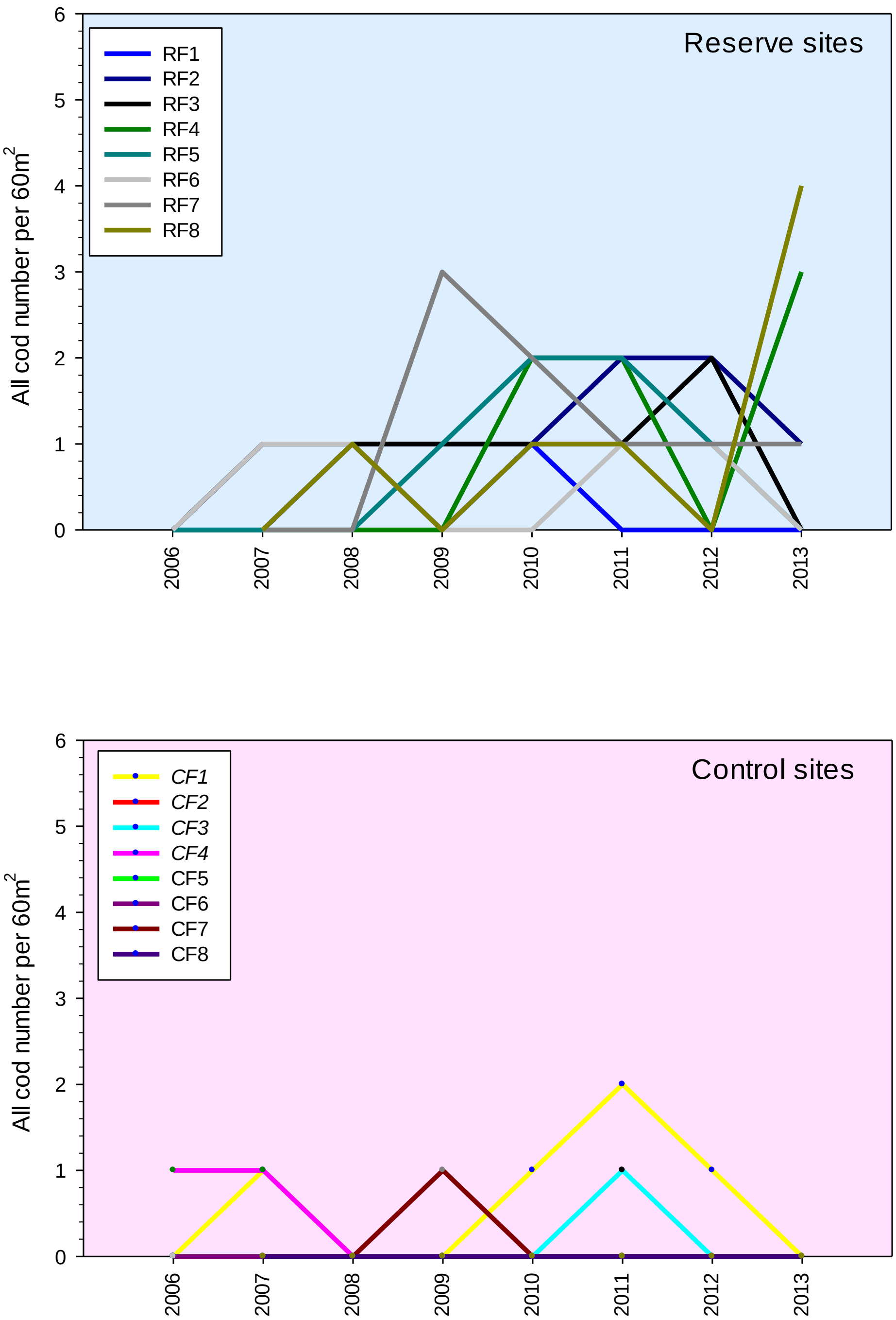


Figure 10. ***Total number of large blue cod pooled across replicate transects (n = 6 in 2006 and 8 in 2007-13) at each site from 2006 to 2013.***

4.6 Lobster density

The density of lobsters at reserve and control sites was comparable between 2006 and 2010 (Figure 11). From 2011, lobster density increased in the reserve sites, peaking in February 2012. No corresponding increase was observed at the control sites where lobster densities remained at relatively low levels throughout the study. In 2012, there were 7.5 times more lobsters in the reserve compared to the control treatment; however, this dropped to 3.5 times in 2013.

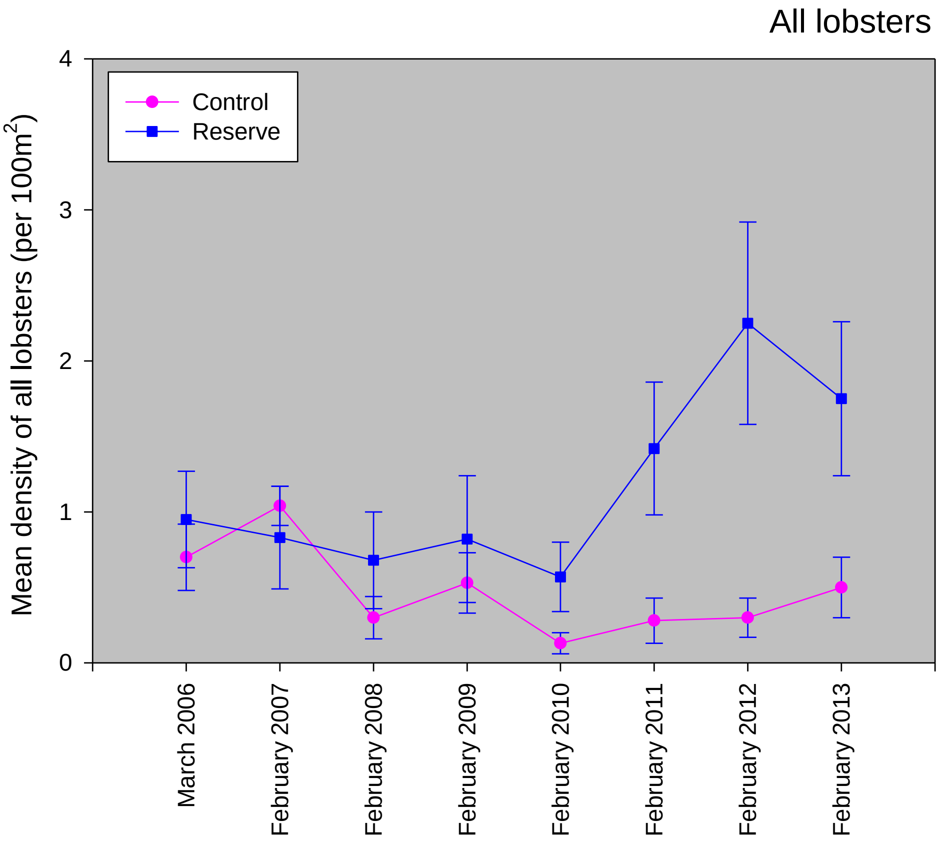


Figure 11. Mean lobster density within Horoirangi reserve (blue squares) and at adjacent control sites (pink circles). Reserve start date is January 2006. Error bars = +/- 1 s.e.

4.7 Large versus small lobsters

Lobsters were classified as being large (≥100 mm carapace length) or small (<100 mm carapace length). A carapace length of 100 mm approximates the legal size limits specified in the recreational fisheries regulations for this region (54 mm tail width for males and 60 mm tail width for females).

The carapace length of a small proportion of lobsters used in density calculations in Figure 11 could not be determined. In 2006 the percentage of lobsters that could not be sexed was an all time high at 30%, however in most years it was < 5%. In 2007, 2008, 2011, 2012, 2013 all lobsters were sexed. The non-sexable individuals were excluded from analyses between large and small size classes. Consequently, the number of large and small lobsters does not provide a precise density measurement for these size classes; however, it provides a close approximation of the relative density of the two size classes at control and reserve sites in Figure 12.

Between 2006 and 2010, the number of small lobsters did not significantly differ between reserve and control sites. From 2011, the density of small lobsters was greater inside the reserve than at adjacent control sites (Figure 12). A similar pattern was recorded for large lobsters, however, between 2006 and 2010 the reserve consistently supported more large lobsters, but this only became significant after 2011 when their numbers increased at the reserve and remained relatively low at the control treatment (Figure 12).

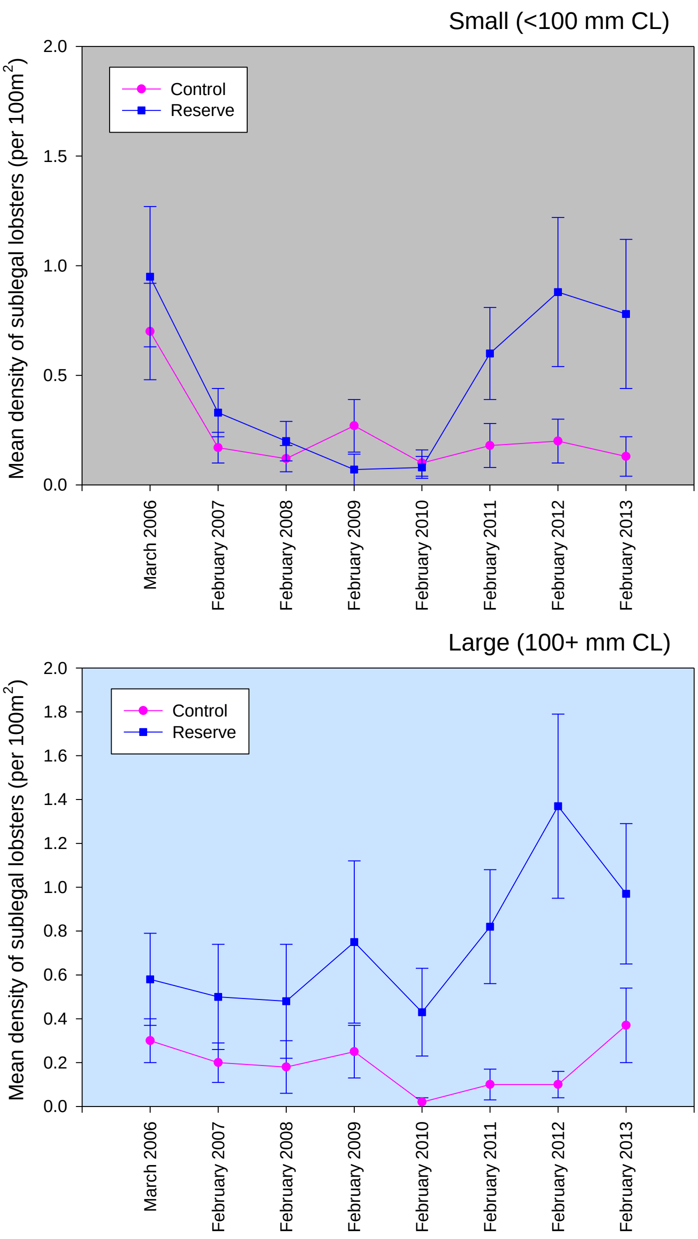


Figure 12. Mean density of small (top) and large (bottom) lobsters within Horoirangi reserve (blue squares) and at adjacent control sites (pink circles). Reserve start date is January 2006. Error bars = +/- 1 s.e.

4.8 Mean lobster size

In 2006, lobsters were significantly larger on average in control sites than reserve sites (P = 0.003; Figure 13). In 2007 and 2008, mean lobster size did not significantly differ between reserve and control sites (P = 0.687 and P = 0.816, respectively). However, in 2009, 2010 and 2012, mean lobster size was significantly larger in reserve sites than control sites (P < 0.025 in all years). Similarly, in 2011 there was a non-significant trend for mean lobster size to be larger in reserve sites than control sites (P = 0.602; Figure 13). In 2013, there was no detectable difference in the mean size of lobsters between reserve and control sites (Figure 13).

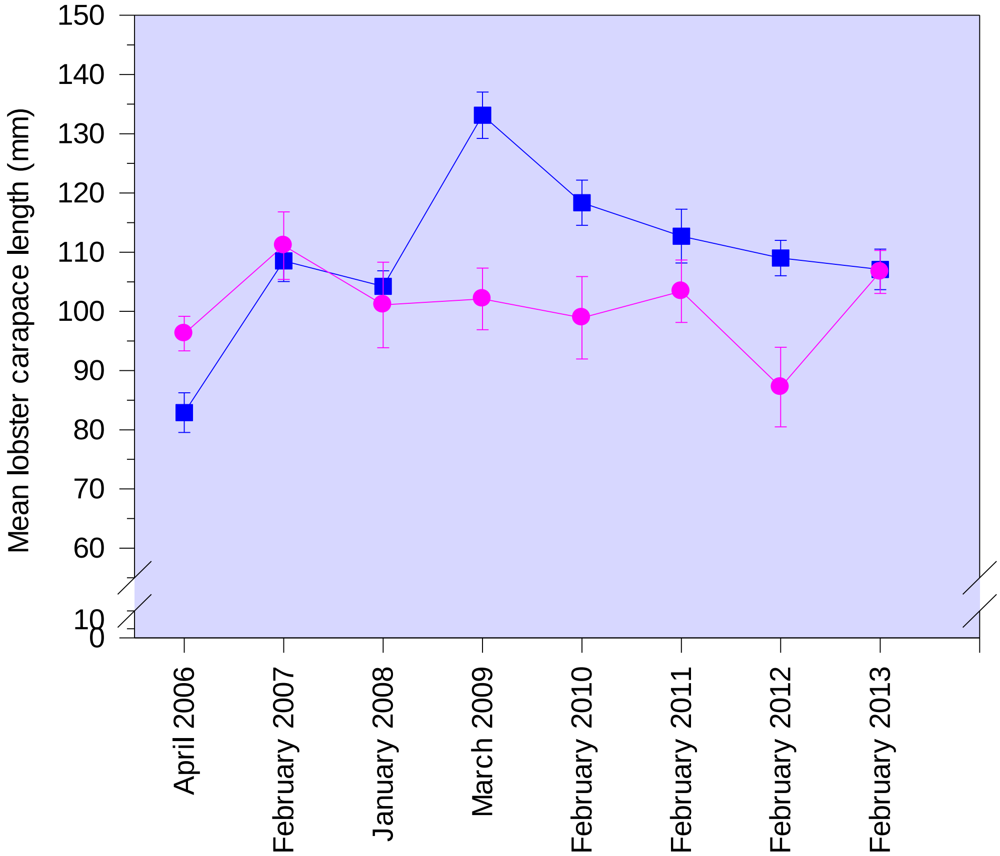


Figure 13. ***Mean lobster size within Horoirangi reserve (blue squares) and at adjacent control sites (pink circles). Reserve start date is January 2006. Error bars = +/- 1 s.e.***

4.9 Lobster size-frequency

In 2006, small individuals dominated the lobster population in the reserve (Figure 14). All but one lobster in the reserve was under 130 mm carapace length (CL), with the majority under 90 mm CL. At control sites, the size range of lobsters recorded was comparable to reserve sites; however, the control sites supported higher numbers of lobsters over 90 mm CL than reserve sites (Figure 14). The mean size of lobsters was therefore higher at control sites than reserve sites (Figure 13).

In 2007 there was an increase in the number of lobsters over 90 mm within the reserve, raising the average size from 82.9 mm to 108.5 mm CL (Figures 13 and 14). An increase in the number of large lobsters also occurred at control sites, with a corresponding increase in mean lobster size.

Most lobsters were greater than 90 mm CL at both reserve and control sites in 2008 and 2009 (Figure 15). However, in 2009 the size structure of lobsters over 90 mm CL differed between reserve and control sites. At reserve sites, lobsters over 90 mm CL were dominated by individuals between 140 and 180 mm CL, whereas in control sites no lobsters were recorded over 160 mm CL (Figure 15). Few individuals with carapace length > 160 mm were recorded in previous years.

From 2010 onwards, the size range of lobsters within the reserve continued to increase with individuals up to 200 mm CL recorded, while lobsters at control sites remained within the 60 to 160 mm CL range (Figures 16 and 17).

In 2011, the first juvenile (<75 mm CL) recruitment event occurred; however, this was confined to the reserve and continued into 2012 and 2013, resulting in a reduction in the mean size of reserve lobsters (Figures 13, 16 and 17). In 2011, the size range of female lobsters in the reserve increased with individuals up to 140 mm CL recorded for the first time (Figure 16). In 2013, lobsters in the reserve were represented by a wider size range, with large males and females regularly observed (Figure 17).

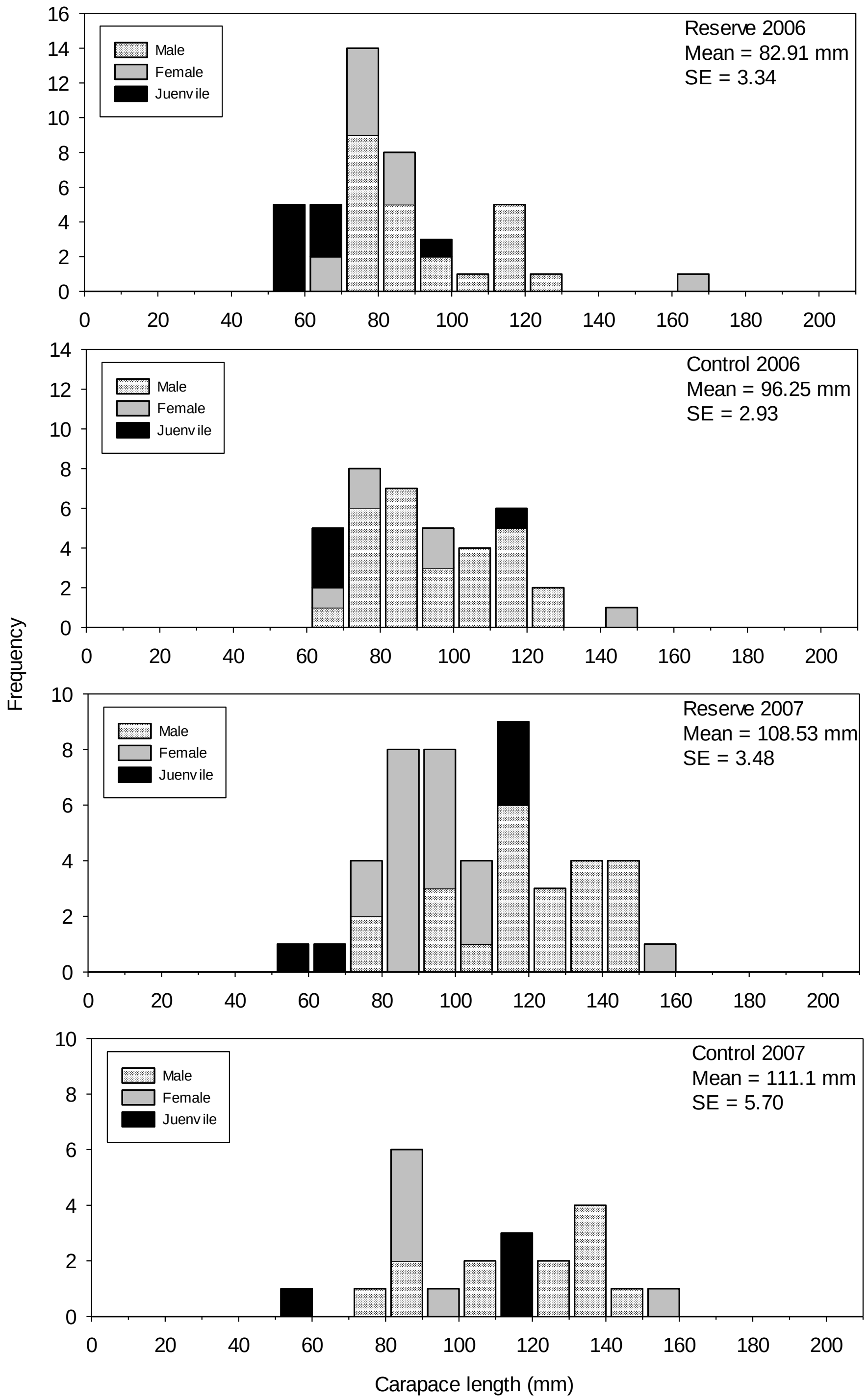


Figure 14. Size-frequency of lobsters within Horoirangi reserve and at adjacent control sites in 2006 and 2007 (juvenile size < 75 mm CL).

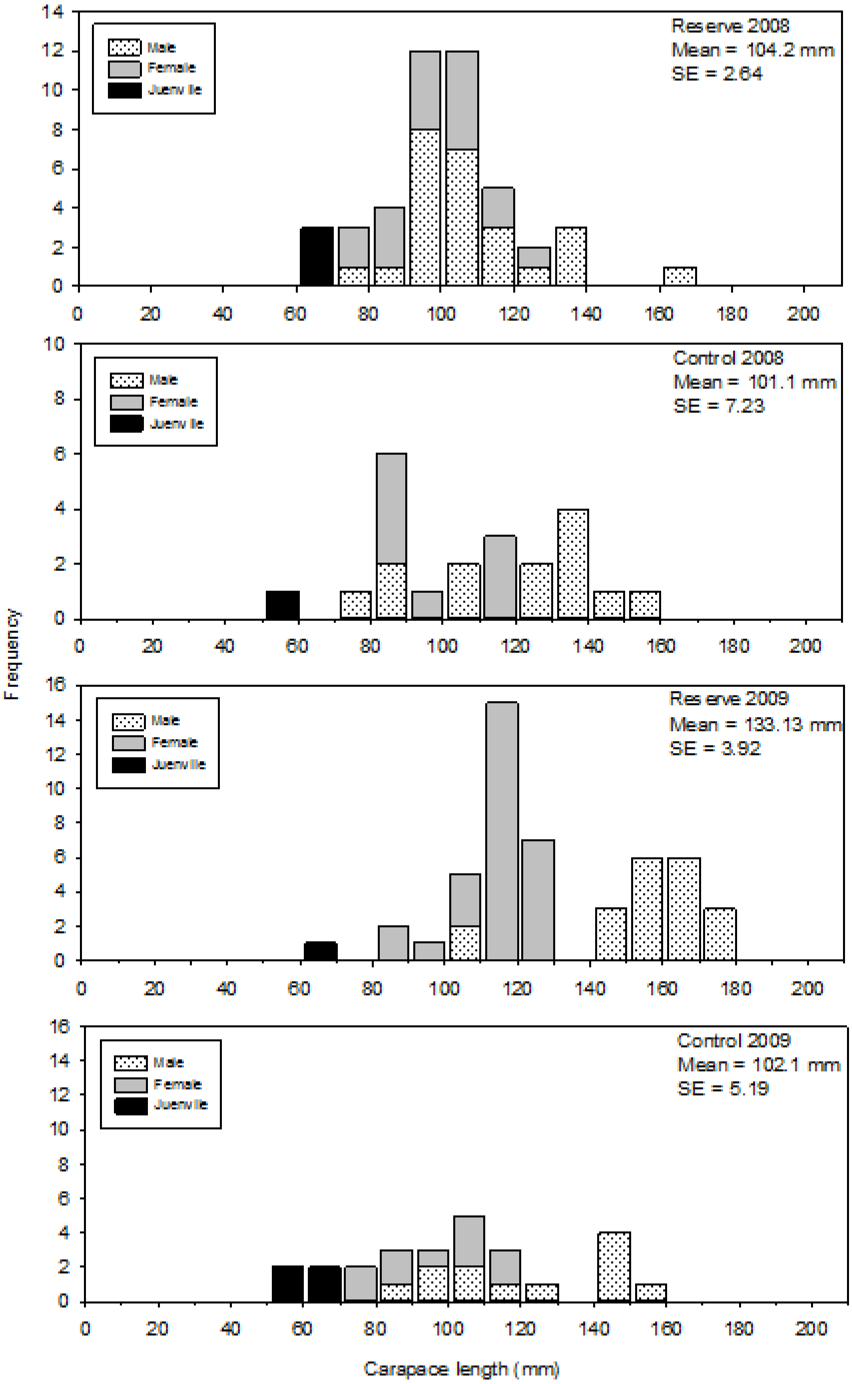


Figure 15. Size-frequency of lobsters within Horoirangi reserve and at adjacent control sites in 2008 and 2009 (juvenile size < 75 mm CL).

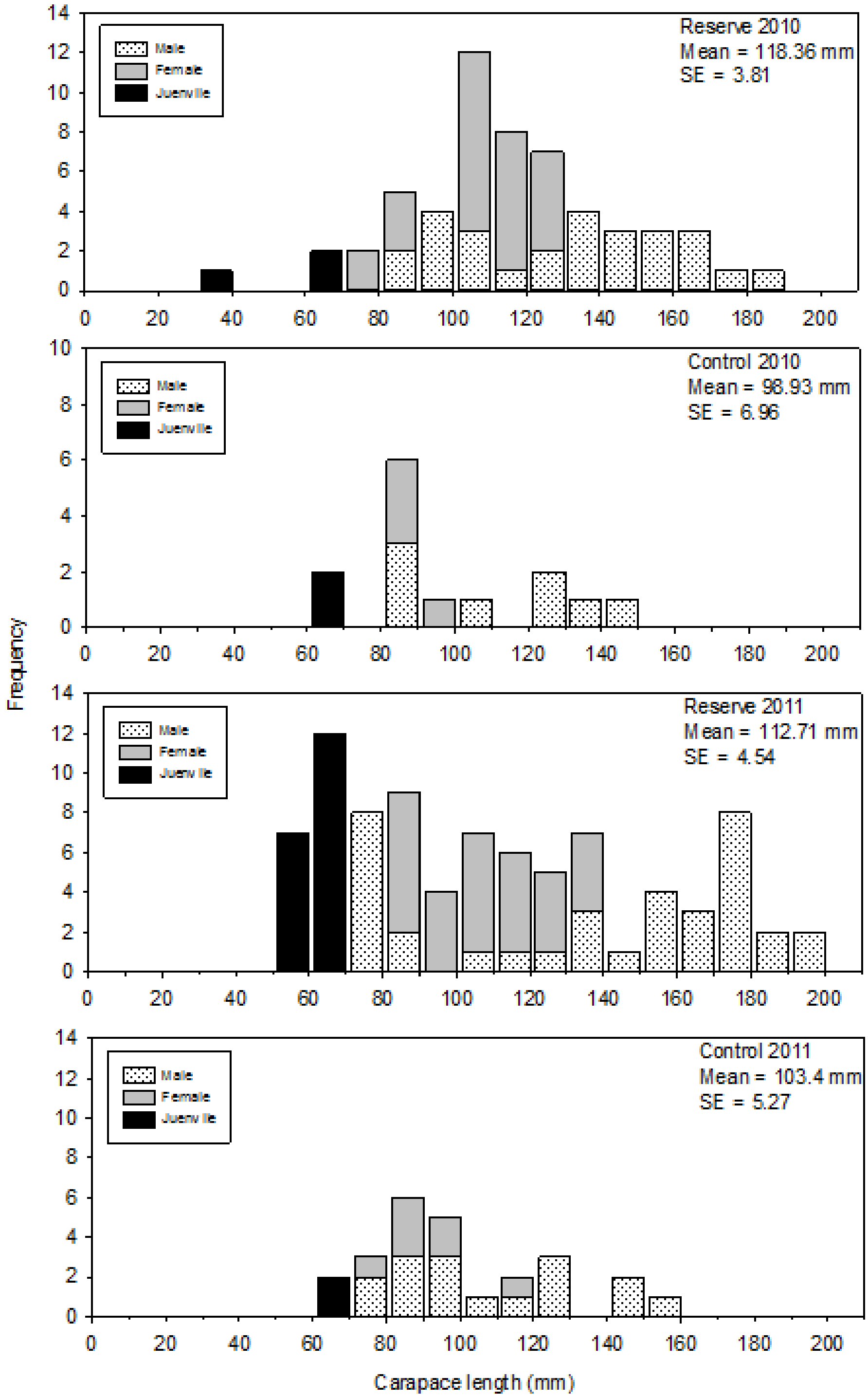


Figure 16. Size-frequency of lobsters within Horoirangi reserve and at adjacent control sites in 2010 and 2011 (juvenile size < 75 mm CL).

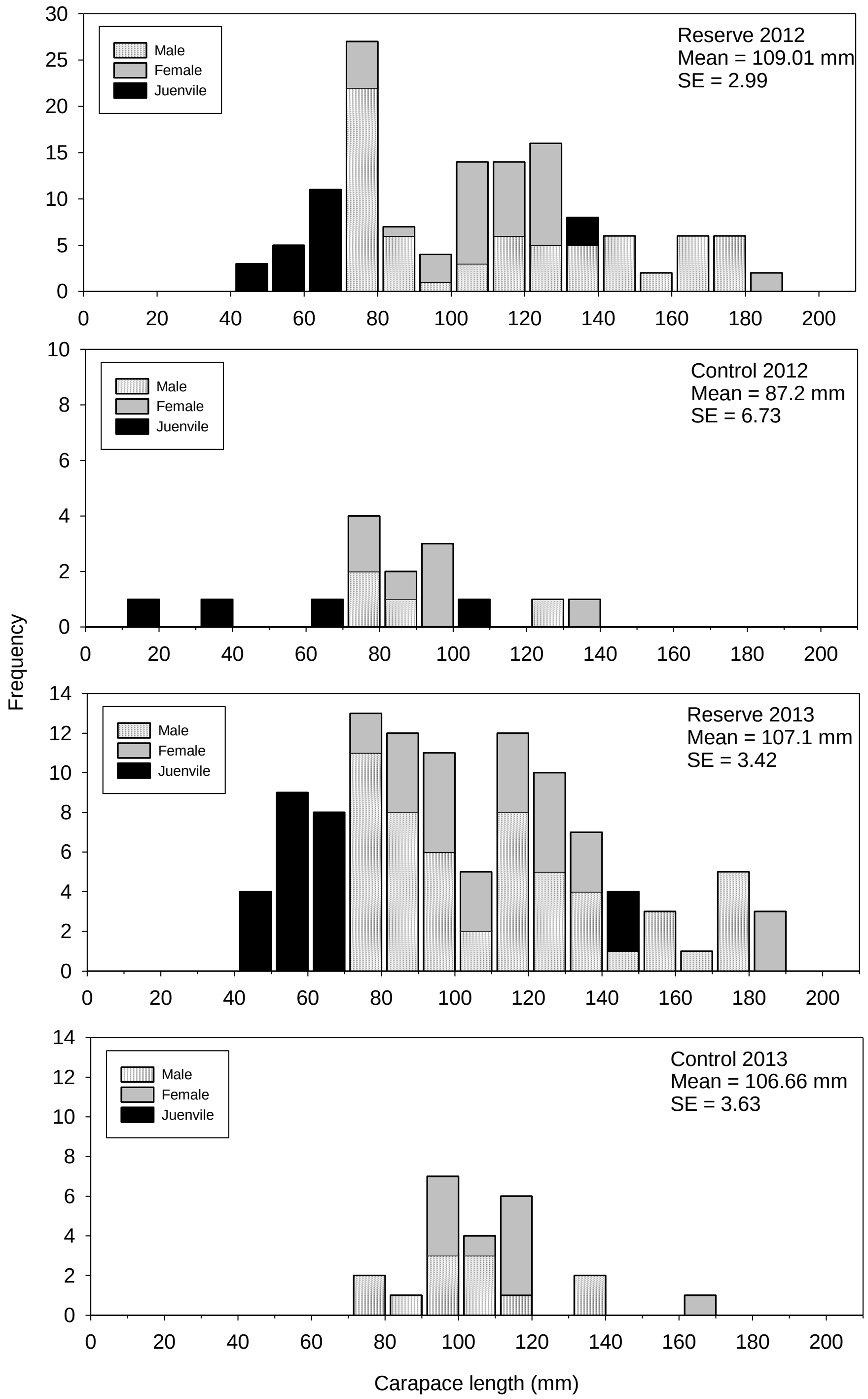


Figure 17. Size-frequency of lobsters within Horoirangi reserve and at adjacent control sites in 2012 and 2013 (juvenile size < 75 mm CL).

4.10 Lobster sex composition

In 2006, proportions of juvenile, female and male lobsters were comparable between reserve and control sites, with a slightly higher percentage of females and lower percentage of males at reserve sites (Figure 18).

In subsequent years, the proportion of females at reserve and control sites generally increased but was usually below the proportion of males. At control sites, the proportion of females has generally remained higher than for the reserve sites. For example, at the end of the study the reserve sites had 27 % females compared to 43.5% at the control sites.

Males were usually the dominant demographic group in the reserve and control populations. In the reserve, males constituted between 38% and 54% of the population, while in control sites males made up between 28 and 73% of the population.

The proportion of juveniles displayed considerable variation between both years, and reserve and control sites. In the reserve, juveniles represented a relatively large proportion in 2006 (25.6 %), dropping to between 4% and 6% from 2007 to 2010. From 2011, the proportion of juveniles in the reserve increased to between 14 and 22% (Figure 18). At control sites, juveniles represented a higher proportion of the population in the years when juveniles were less important at the reserve sites (i.e., 2008-2010). In 2013, no juveniles were recorded from control sites.

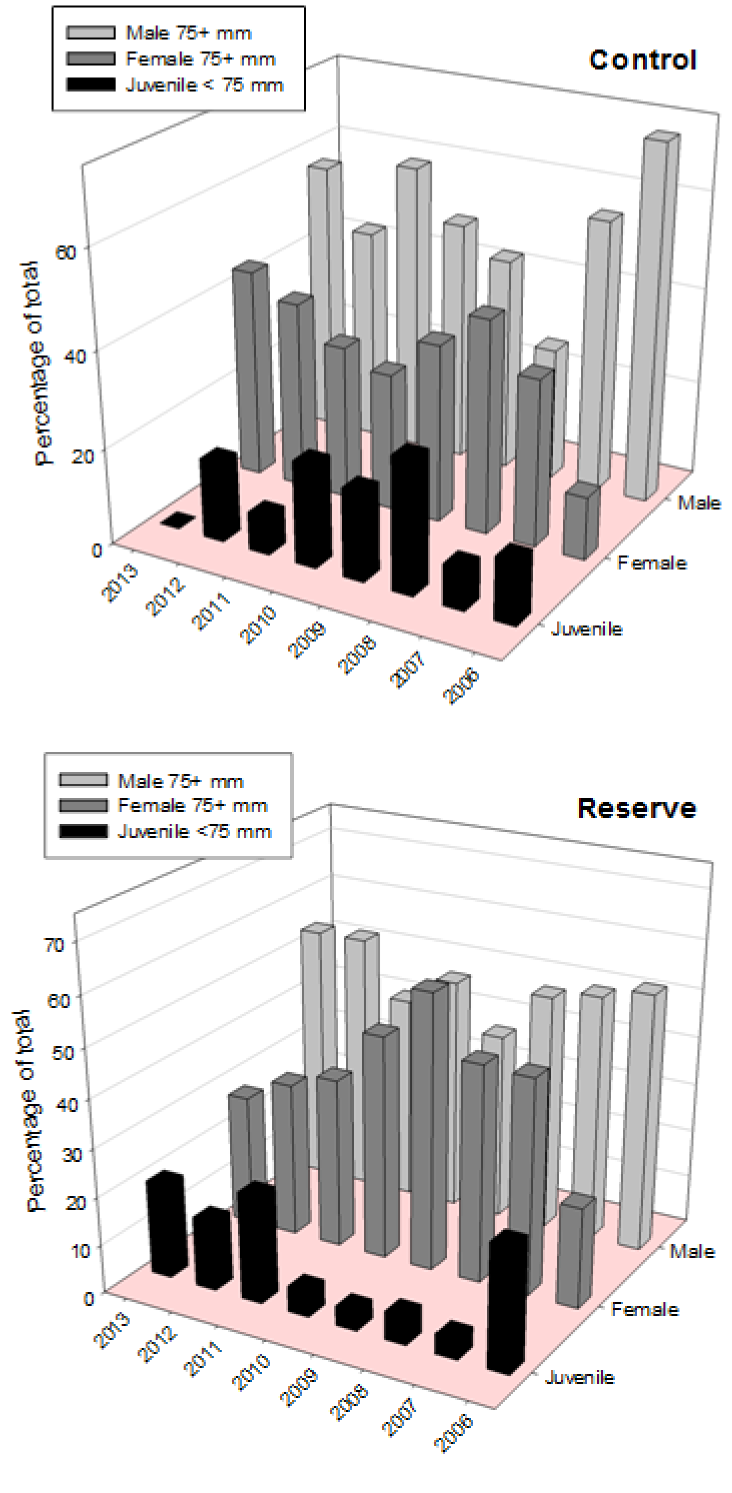


Figure 18. Percentage of the total sexable lobsters within Horoirangi reserve and at adjacent control sites from 2006 to 2013.

4.11 Black foot paua

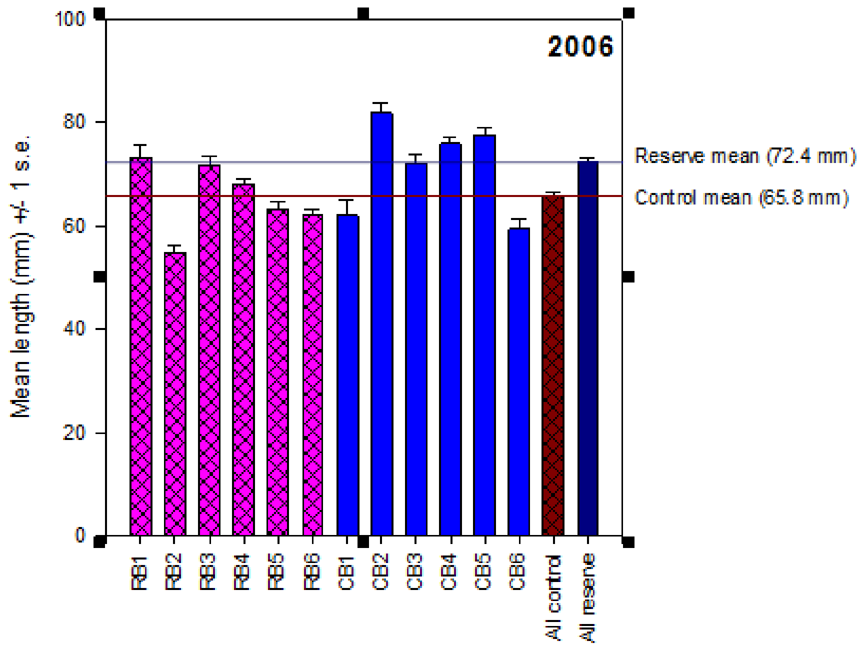
The density and size of paua was sampled in 2006 and again in 2013. In 2006, paua density was quantified in 10 quadrats sampled at six reserve and six control sites. Average density in the same year was 0.32 individuals per m^2 at reserve sites and 0.33 individuals per m^2 in control sites (Table 3). In 2013, density was quantified in a minimum of 30 quadrats at each of the same 12 sites. Average density in 2013 was 1.2 individuals per m^2 in the control sites and 2.02 per m^2 in the reserve sites (Table 3).

The length of paua was quantified in all six control and six reserve sites in 2006 and again in 2013. Paua were classified as being either large sized (=/> 125 mm) or small (< 125 mm) based on the size limits specified in the recreational fisheries regulations for this region.

No large legal sized paua were recorded from either reserve or control sites in either sample year. Black-foot paua in the reserve ranged from 34 mm to 99 mm, while at control sites they ranged from 28 mm to 109 mm. Mean paua length varied both between sites within the reserve and between sites adjacent to the reserve. Unexpectedly, mean length of paua at reserve sites declined between 2006 and 2013 (Figure 19), while the mean length of paua at control sites increased from 2006 to 2013.

Table 3. Mean density and size of paua from reserve and control sites in 2006 and 2013.

Treatment	2006			2013		
	Mean	SE	N	Mean	SE	N
Control density (m^2)	0.33	0.12	60	1.2	0.11	180
Reserve density (m^2)	0.32	0.13	60	2.02	0.15	192
Control length (mm)	65.85	0.86	274	72.9	0.715	282
Reserve length (mm)	72.43	0.75	299	67.28	0.54	389



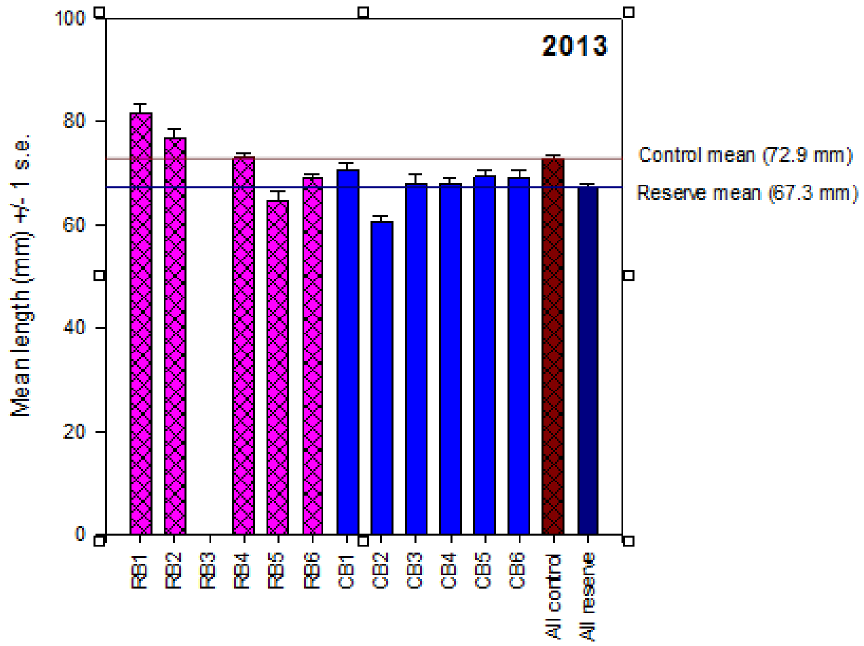


Figure 19. Mean paua length recorded from reserve and control sites and pooled treatments in 2006 and 2013. Error bars are +/- 1 SE. The yellow reference line is set at 70 mm.

5.0 Discussion

5.1 Fish

At the start of the study in 2006, most edible reef fish (blue cod, blue moki, red moki, butterfish) were uncommon at both reserve and control sites. For example, no large blue cod were counted on reserve transects in 2006. By 2013, the abundance of large sized blue cod, and the mean size of all blue cod, was significantly greater in the reserve than at adjacent control sites. In 2013, divers regularly observed large blue cod in the reserve, whereas they were less often observed at control sites.

Blue cod abundance was relatively low compared to Long Island-Kokomohua MR (Davidson 2001; Davidson 2004; Davidson *et al*., 2009), but comparable to the early years at Tonga Island MR (Davidson 1991; Davidson *et al*., 2007). The similarity with Tonga Island MR is probably due to its proximity to Horoirangi MR and its location within the relatively sheltered Tasman Bay marine environment. It is probable that movement of blue cod by immigration from surrounding areas is low for these two reserves, whereas at Long Island, blue cod may commonly immigrate from adjacent areas (Mace and Johnson 1983; Blackwell 1997, 1998; Davidson 2001). Similarly, recruitment also appears to be low at Horoirangi, with very few juveniles observed compared to Long Island. The increase in the abundance of large blue cod in Horoirangi MR was the first change due recorded for this reserve.

For the other edible species of blue moki and tarakihi, no change in abundance was attributable to the reservation. Although blue moki abundance initially increased and then declined during the course of the study, comparable patterns were recorded at control sites. For tarakihi, their abundance was highly variable with no pattern that could be attributed to the reservation. In most years, more and larger tarakihi were recorded at adjacent control sites than inside the reserve. This phenomenon has also been recorded for tarakihi at Long Island-Kokomohua MR (Davidson *et al*., 2009) and Tonga Island MR (Davidson *et al*., 1997).

The mean size and size-frequency data for blue cod showed a change due to reservation, with a greater mean size and greater proportion of large blue cod recorded from within the reserve in the latter years of the study compared to control sites. In contrast, the mean size of blue moki initially declined at both reserve and control sites, followed by partial recovery both within and outside the reserve, suggesting that relative to controls the reserve had not increased the abundance of legal sized blue moki. The average size of tarakihi remained relatively constant in the reserve, but increased and then dramatically declined at the control sites. This was influenced by the abundance of large individuals in the 17-28 cm size class. When present, they lead to an increase in the mean length of tarakihi. Tarakihi in the 17-28 cm size class were more often observed from control sites; however, the number of these larger fish fluctuated from year to year. Small individuals were recorded in all years from both control and reserve sites, suggesting good recruitment success each year.

Some reserve sites regularly had a high abundance of blue cod while others regularly had a low abundance. This phenomenon also occurred at control sites. The reasons for these differences may be related to environmental variables such as tidal currents, substratum and food. In a monitoring study of Long Island-Kokomohua MR, some reserve sites regularly supported greater numbers of blue cod than other reserve sites (Davidson *et al*., 2009). Davidson *et al.,* (2009) also commented that these same sites often also supported higher densities of small blue cod.

Of the reef fish found in Horoirangi MR, blue cod have been the first to respond to reservation. Cole *et al*., (2002) suggested that blue cod responded positively to initiation of marine reserves due to their often small home ranges. The authors stated that even relatively small marine reserves could prove successful for blue cod with corresponding increases in their abundance and size. The present study supports this conclusion – the mean length of blue cod, and the abundance of individuals meeting legal limits specified in the recreational fisheries regulations for this region both increased inside Horoirangi MR, which is small relative to other marine reserves.

5.2 Lobster

Relative to control sites, the abundance of spiny lobsters within the reserve remained relatively low for the first five years after the implementation of the reserve. This was not unexpected, as little or no change in lobster abundance occurred at Long Island-Kokomohua MR and Tonga Island MR in the first five to seven years after the implementation of these reserves (Davidson *et al*., 2007, 2009, 2013). This slow start by lobsters has also been recorded at most marine reserves in New Zealand (Freeman *et al*., 2012). The increase in lobster abundance has often been associated with larval recruitment events that vary both spatially around New Zealand and temporally between years (Freeman *et al*., 2012). An increase in abundance may also be related to the gregarious behaviour of lobsters (Kelly 1999, 2001; Kelly *et al*., 1999). The physical presence of lobsters at a location may attract other lobsters or encourage migrating lobsters to remain rather than continue their movement through an area (Davidson *et al*., 2002).

The abundance of large lobsters should increase at a faster rate within the reserve compared to fished areas as fishers in non-reserve sites remove large lobsters. The removal of large lobsters will therefore emphasize increases within the protected area compared to adjacent fished areas. Analysis of the abundance of large lobsters within and outside Horoirangi MR showed that large lobsters were less often encountered at control sites, compared to a slow but steady increase within the reserve. In 2013, lobsters were 3.5 times more abundant in the reserve compared to outside the reserve, despite the absence of lobsters from two of the eight reserve sites.

In the first five years, the abundance of small lobsters within the reserve declined while the abundance of large individuals within the reserve increased. The increase in large lobsters was probably due to small lobsters moulting and growing through to the large size class (>100 mm CL). The decline in the abundance of small lobsters in the reserve (and at control sites) suggests that little no recruitment or migration into these areas occurred over this period. Size-frequency data confirms that large lobsters in the reserve grew through from the small size individuals over the duration of the study. It was only in 2011-2013 that a pulse of juveniles appeared in the reserve population; however, this phenomenon only occurred in the reserve, with few juveniles recorded from the control sites in the same years. The increase in the number of juvenile lobsters in the reserve also acted to reduce the mean size of lobsters down to control levels. The reason for the lack of recruitment at control sites in these years is unknown, but may be related to the gregarious nature of lobsters, with small lobsters choosing to inhabit areas with adult lobsters. Free-swimming larval lobsters may also choose to settle and remain in areas where adult lobsters are present or may move to these areas after they have settled.

The increase in abundance of large lobsters combined the change in the size structure of lobster population in the reserve are strong indicators that the reserve has had a positive impact on the North Nelson lobster population. This result, although relatively minor compared to changes that have been documented for older marine reserves in New Zealand, has been emphasized by the low numbers of lobsters, especially large individuals, found in areas adjacent to Horoirangi MR.

5.3 Black foot paua

Although small in size, black foot paua were common at both reserve and control sites. No large paua were recorded at reserve or control sites, and this may be related to wave energy or the energy component of available food sources. There was some suggestion from mean size data that the largest paua were present from northeastern sites. Whether this was due to more wave exposure or a better quality of food is uncertain. No paua aging work has been conducted in Tasman Bay, so the age of the larger paua in the population remains unknown. The lack of paua reaching legal limits (125 mm) may mean that the largest and probably oldest individuals in this population are stunted. Stunted paua area also known for other areas of New Zealand including north of Auckland, Taranaki, Gisborne, Hawke's Bay, northern Banks Peninsula and Karitane (Schiel and Breen 1991, Naylor and Andrew 2000; Naylor and Andrew 2004). The reasons why stunted populations do not reach the legal limit are unknown, but are likely to be related to environmental conditions such as food availability and quality, wave exposure, currents and density-dependent factors.

In 2013, the densities of paua at both reserve and control densities had increased from 2006; however, this may be an artifact of the number of quadrats sampled on each occasion. In 2013, 30 quadrats were sampled compared to 10 in 2006. If the distribution of paua is spatially patchy, sampling a larger area in 2013 may provide a more accurate quantitative assessment of paua density.

At both control and reserve sites, paua were restricted to the shallow subtidal (0-2 m depth: Plate 4). No paua were observed by divers at greater depths. Their small size and preference to live near low water may reflect distribution patterns of food availability and higher wave energy in the shallows. Most macroalgae and erect coralline algae were located near low water along this coast (Plate 4).

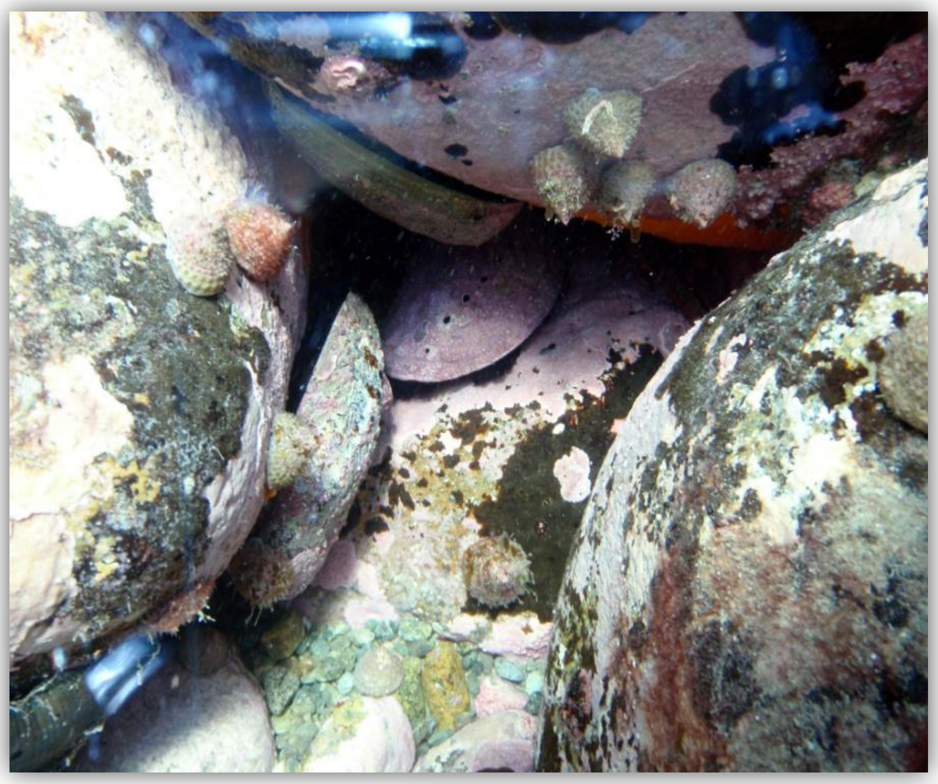


Plate 4. Black foot paua under boulders (top) and shallow boulder habitat present at many sites (right).

6.0 Recommendations for monitoring and study

Based on data collected in the present study, Horoirangi Marine Reserve appears to be in a state of change, with substantial increases in the density and size of lobsters and blue cod occurring. It is therefore recommended that annual monitoring of reef fish and lobsters continue.

Other species may also change in the future; although, it is too soon to determine which species these may be. Based on other long-term marine reserve monitoring studies the potential candidates for intermittent monitoring are listed below.

- Kina density and size
- Macroalgae cover and distribution
- Paua density and size

The stunted paua population is of scientific interest and warrants investigation. This would not be part of any monitoring programme, but should be supported in an effort to determine why they do not reach legal size. Areas of investigation could include:

- Ageing (if aging techniques become more reliable) throughout Tasman Bay.
- Investigate paua size versus environmental variable such as wave exposure and food quality throughout Tasman Bay.
- Transplant experiments from areas where paua are large to areas where they are stunted and visa versa.
- Exclusion experiments (i.e., kina, molluscan grazers).

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References

Arrenguin – Sanchez, F. 1996. Catchability: a key parameter for fish stock assessment. Review Fisheries Biology Fish 6: 221-242.

Bell, J.D. 1983. Effects of depth and marine reserve fishing restrictions on the structure of a rocky reef fish assemblage in the northwestern Mediterranean Sea. Journal of Applied Ecology 20: 357-369.

Bennett, B.A. and Attwood, C.G. 1991. Evidence for recovery of a surf-zone fish assemblage following the establishment of a marine reserve on the southern coast of South Africa. Marine Ecology Progress Series 75: 173-181.

Bennett, B.A. and Attwood, C.G. 1993. Shore-angling catches in the DeHoop Nature Reserve, South Africa. South African Journal of Marine Science 13: 213-222.

Blackwell, R.G. 1997. Abundance, size composition, and sex ratio of blue cod in the Marlborough Sounds, September 1995. New Zealand Fisheries Data Report 88, NIWA, Wellington. 17p.

Blackwell, R.G. 1998. Abundance, size and age composition, and yield-per-recruit of blue cod in the Marlborough Sounds, September 1996. NIWA Technical Report 30. 47p.

Buxton, C.D. and Smale, M.J. 1989. Abundance and distribution patterns of three temperate fish in exploited and unexploited areas off the southern Cape coast. Journal of Applied Ecology 26: 441-451.

Carbines, G. 1998. Determination of movement of blue cod in Southland. Final Research Report for Ministry of Fisheries. NIWA, Wellington. 14p.

Carbines, G. 1999. Determination of movement of blue cod in Southland. Final Research Report for Ministry of Fisheries. NIWA, Wellington. 20p.

Cole, R.G. 1994. Abundance, size structure, and diver-oriented behaviour of three large benthic carnivorous fishes in a marine reserve in northeastern New Zealand. Biological Conservation 70: 93-99.

Cole, R.G., Ayling, T.M., and Creese, R.G. 1990. Effects of marine reserve protection at Goat Island, northern New Zealand. New Zealand Journal of Marine and Freshwater Research 24: 197-210.

Cole, R.G., Creese, R.G., Grace, R.V., Irving, P., and Jackson, B. 1992. Abundance patterns of subtidal benthic invertebrates and fishes at the Kermadec Islands. Marine Ecology Progress Series 82: 207-218.

Cole, R.G., Villouta, E., and Davidson, R.J. 2000. Direct evidence of limited dispersal of the reef fish *Parapercis colias* (Pinguipedidae) within a marine reserve and adjacent fished areas. Aquatic Conservation: Freshwater and Marine Ecosystems 10: 421-436.

Cole, R., Grange, K., and Morrisey, D. 2003. Marine habitats, fish and benthic species within a proposed marine reserve, North Nelson. NIWA report NEL2003-005 prepared for Department of Conservation, Nelson.

Davey, N., Bradley, A., and Grange, K. 2005. Habitat mapping of Wakapuaka Taiapure. NIWA client report Nel2005-023 prepared for Department of Conservation, Nelson.

Davidson, R.J.; Richards, L.A. 2013. Tonga Island Marine Reserve, Abel Tasman National Park update of biological monitoring, 1993 – 2013. Prepared by Davidson Environmental

Limited for Department of Conservation, Nelson. Survey and Monitoring Report No. 771.

Davidson, R.J., Abel, W., and Richards, L.A. 2009: Biological monitoring update 1992-2009: Long Island-Kokomohua Marine Reserve, Queen Charlotte Sound. Prepared by Davidson Environmental Limited for Department of Conservation, Nelson. Survey and Monitoring Report No. 573.

Davidson, R., Richards, L., and Baxter, A. 2007. Tonga Island Marine Reserve, Abel Tasman National Park update of biological monitoring, 1993-2007. Prepared by Davidson Environmental Limited for Department of Conservation, Nelson. Survey and Monitoring Report No. 484.

Davidson, R.J. and Richards L.A. 2005. Comparison of fish at reserve and control sites from Long Island-Kokomohua and Tonga Island Marine Reserves using baited underwater video (BUV), catch, measure, release (CMR) and underwater visual counts (UVC). Prepared by Davidson Environmental Limited for Department of Conservation, Nelson. Survey and Monitoring Report No. 466.

Davidson, R.J. 2006. Horoirangi Marine Reserve, North Nelson, rocky shore baseline biological report. Prepared by Davidson Environmental Limited for Department of Conservation, Nelson. Survey and Monitoring Report No. 513.

Davidson, R.J. 2004. Long Island-Kokomohua Marine Reserve, Queen Charlotte Sound: 1992-2003. Prepared by Davidson Environmental Limited for Department of Conservation, Nelson. Survey and Monitoring Report No. 343.

Davidson, R.J. 2001. Changes in population parameters and behaviour of blue cod (*Parapercis colias*) in Long Island-Kokomohua Marine Reserve, Marlborough Sounds, New Zealand Aquatic Conservation: Marine & Freshwater Ecosystems 11: 417-435.

Davidson, R.J. 1997. Biological monitoring of Long Island-Kokomohua Marine Reserve, Queen Charlotte Sound, Marlborough Sounds: update September 1993-April 1997. Prepared for the Department of Conservation by Davidson Environmental Ltd. Survey and Monitoring Report No. 150. 40p.

Davidson, R.J. 1992. A report on the intertidal and shallow subtidal ecology of the Abel Tasman National Park, Nelson. Department of Conservation, Nelson/Marlborough Conservancy Occasional Publication. No. 4, 161 p.

Davidson, R.J. 1991. Tonga Island Marine Reserve: proposed protocol for ongoing subtidal biological monitoring. Prepared for the Department of Conservation by Davidson Environmental Ltd. Survey and Monitoring Report No. 316. 29p.

Davidson, R.J. and Chadderton, W.L. 1994. Marine reserve selection along the Abel Tasman National Park coast, New Zealand: consideration of subtidal rocky communities. Aquatic Conservation: Freshwater and Marine Ecosystems 4: 153-167.

Davidson, R.J., Villouta, E., Cole, R.G., and Barrier, R.G.F. 2002. Effects of marine reserve protection on spiny lobster abundance and size at Tonga Island Marine Reserve, New Zealand. Aquatic Conservation: Marine and Freshwater Ecosystems 12: 213-227.

Denny, C.M. and Babcock, R.C. 2004. Do partial marine reserves protect reef fish assemblages? Biological Conservation 116: 119–129.

Denny, C.M., Willis, T.J., and Babcock, R.C. 2004. Rapid recolonisation of snapper *Pagrus auratus*: Sparidae within an offshore island marine reserve after implementation of no-take status. Marine Ecology Progress Series 272: 183–190.

Edgar, G.J. and Barrett, N.S. 1999. Effects of the declaration of marine reserves on Tasmanian reef fishes, invertebrates and plants. Journal of Experimental Marine Biology and Ecology 242: 107-144.

Freeman, D. 2006. Te Angiangi and Te Tapuwae o Rongokako Marine Reserves: intertidal paua and kina monitoring. Report prepared by Department of Conservation, Technical Report No. 26.

Freeman, D. 2005. Reef fish monitoring: Te Tapuwae o Rongokako Marine Reserve. Report prepared by Department of Conservation, Technical Report No. 25.

Freeman D.J., MacDiarmid A.B., Taylor R.B., Davidson R.J., Grace R.V., Haggitt T.R., Kelly S., Shears N.T. 2012. Trajectories of spiny lobster *Jasus edwardsii* recovery in New Zealand marine protected areas – is settlement a driver? Environmental Conservation 39: 295-304.

Freeman D.J., Breen P.A., MacDiarmid A.B. 2012a. Use of a marine reserve to determine the direct and indirect effects of fishing on growth in a New Zealand fishery for the spiny lobster *Jasus edwardsii*. Canadian Journal of Fisheries and Aquatic Sciences 69: 894-905.

Freeman, D.J. and MacDiarmid, A.B. 2009. Healthier lobsters in a marine reserve: effects of fishing on disease incidence in the spiny lobster, *Jasus edwardsii*. Marine and Freshwater Research 60(2): 140–145.

Freeman, D.J. and Duffy, C.A.J. 2003. Te Angiangi Marine Reserve: Reef fish monitoring 1995-2003. Department of Conservation, East Coast Hawke's Bay Conservancy, Technical Series No. 14.

Garcia-Rubies, A. and Zabala, M. 1990. Effects of total fishing prohibition on the rocky fish assemblages of Medes Islands marine reserve (MW Mediterranean). Scientifica Marina 54: 317-218.

Guisado D.D., Cole R.G., Davidson R.J., Freeman D.J., Kelly S., Macdiarmid A., Pande A., Stewart R., Struthers C., Bell J.J., Gardner G.P.A. 2012. Comparison of methodologies to quantify the effects of age and area of marine reserves on the density and size of targeted species. Aquatic Biology 14: 185-200.

Hilborn, R., Stokes, K., Maguire, Jean-Jacques, Smith, T., Botsford, W., Mangel. M., Orensanz, J., Parma, A., Rice, J., Bell, J., Cockrane, L., Garcia, S., Hall, S.J., Kirkwood, G.P., Sainsbury, K., Stefansson, G., and Walters, C. 2004. When can marine reserves improve fisheries management? Ocean and Coastal Management 47: 197-205.

Jennings, S. and Polunin, N.V.C. 1995. Biased underwater visual census biomass estimates for target-species in tropical reef fisheries. Journal of Fish Biology 47: 733-736.

Jones, G.P., Cole, R.C. and Battershill, C.N. 1993. Marine reserves: do they work? Pp. 15-22 in Battershill et al. (eds): Proceedings of the Second International Temperate Reef Symposium, 7-10 January 1992, Auckland, New Zealand. NIWA Marine, Wellington. 252p.

Kelly, S. 1999. Marine reserves and the spiny lobster, *Jasus edwardsii*. Unpublished Ph.D thesis, University of Canterbury.

Kelly, S. 2001. Temporal variation in the movement of the spiny lobster *Jasus edwardsii*. Marine and Freshwater Research 52: 323-331.

Kelly, S., MacDiarmid, A.B., and Babcock, R.C. 1999. Characteristics of spiny lobster, *Jasus edwardsii*, aggregations in exposed reef and sandy areas. Marine and Freshwater Research 50: 409-416.

Kelly, S., Scott, D., MacDiarmid, A.B., and Babcock, R.C. 2000. Spiny lobster, *Jasus edwardsii*, recovery in New Zealand marine reserves. Biological Conservation 92: 359-369.

Kulbicki, M. 1998. How the acquired behaviour of commercial reef fishes may influence the results obtained from visual censuses. Journal of Experimental Marine Biology and Ecology 222: 11 – 30.

Lipcius, R.N. and Cobb, J.S. 1994. Ecology and fishery biology of spiny lobsters. In: Spiny lobster management. Phillips et al. (eds.). Blackwell Scientific: London. Chapter 1.

McCormick, M.I. and Choat, J.H. 1987. Estimating total abundance of a large temperate-reef fish using visual strip transects. Marine Biology 96: 469-478.

MacDiarmid, A.B. 1989. Size at onset of maturity and size dependent reproductive output of female and male spiny lobsters *Jasus edwardsii* (Hutton) (Decapoda, Palinuridae) in northern New Zealand. Journal of Experimental Marine Biology and Ecology 89: 191-204.

MacDiarmid, A.B. and Breen, P.A. 1993. Spiny lobster population change in a marine reserve. Pp. 15-22 in Battershill. et al. (eds): Proceedings of the Second International Temperate Reef Symposium, 7-10 January 1992, Auckland, New Zealand. NIWA Marine, Wellington. 252p.

MacDiarmid, A.B. and Butler, M.J. 1999. Sperm economy and limitation in spiny lobsters. Behavioral Ecology and Sociobiology 46: 14-24.

Mace, J.T. and Johnson, A.D. 1983. Tagging experiments on blue cod (*Parapercis colias*) in the Marlborough Sounds, New Zealand. New Zealand Journal of Marine and Freshwater Research 17: 207-211.

Naylor, J.R.; Andrew, N.L. 2004. Productivity and response to fishing of stunted paua stocks. New Zealand Fisheries Assessment Report 2004131. 17p.

Naylor, J.R.; Andrew, N.L. 2000. Determination of growth, size composition, and fecundity of paua at Taranaki and Banks Peninsula. New Zealand Fisheries Assessment Report. 2000/51 25 p.

Pande, A., MacDiarmid, A.B., Smith, P.J., Davidson, R.J., Cole, R.G., Freeman, D., Kelly, S., and Gardner, P.A. 2008. Marine reserves increase the abundance and size of blue cod and rock lobster. Marine Ecology Progress Series 366: 147-158.

Shears, N.T., Grace, R.V., Usmar, N.R., Kerr, V., and Babcock, R. 2006. Long-term trends in lobster populations in a partially protected vs. no-take Marine Park. Biological Conservation 132: 222-231.

Schiel, D.R.; Breen, P.A. 1991. Population structure, ageing, and fishing mortality of the New Zealand abalone *Haliotis iris*. Fishery Bulletin 89: 68 1-69 1 .

Underwood, A.J. 1993. The mechanics of spatially replicated sampling programmes to detect environmental impacts in a variable world. Australian Journal of Ecology 18: 99-116.

Willis, T.J. 2000. Te Whanganui A Hei fish monitoring Program: II. Change in Snapper and blue cod density. Report to the Department of Conservation, August 2000.

Willis, T.J. and Millar, R.B. 2005. Using marine reserves to estimate fishing mortality. Ecology Letters 8: 47-52.

Willis, T.J., Millar, R.B, and Babcock, R.C. 2000. Detection of spatial variability in relative density of fishes: comparison of visual census, angling, and baited underwater video. Marine Ecology Progress Series 198: 249-260.

Willis, T.J., Millar, R.B., Babcock, R.C., and Tolimieri, N. 2003. Burdens of evidence and the benefits of marine reserves for fisheries management: putting Descartes before des horse? Environmental Conservation 30: 97–103.

Appendix 1. Blue cod numbers recorded from diver transects between 2006 and 2013.

Sites (all blue cod)	Treatment	2006	2007	2008	2009	2010	2011	2012	2013
RF1	Reserve	1	0	2	2	2	0	0	1
RF2	Reserve	0	1	3	3	10	7	4	16
RF3	Reserve	1	4	5	4	3	6	6	6
RF4	Reserve	1	0	0	0	2	2	0	3
RF5	Reserve	1	0	0	1	2	3	2	4
RF6	Reserve	0	2	1	0	0	2	2	3
RF7	Reserve	NA	2	5	7	4	8	5	5
RF8	Reserve	NA	0	4	0	3	7	1	7
CF1	Control	0	5	1	1	5	8	8	7
CF2	Control	1	0	0	0	0	0	2	4
CF3	Control	0	0	4	5	4	4	18	9
CF4	Control	1	1	0	1	0	0	2	3
CF5	Control	2	1	10	5	1	3	4	2
CF6	Control	1	1	1	0	0	0	2	0
CF7	Control	NA	0	0	1	0	0	1	0
CF8	Control	NA	0	0	7	9	0	42	10

Sites (<30cm blue cod)	Treatment	2006	2007	2008	2009	2010	2011	2012	2013
RF1	Reserve	1	0	2	2	1	0	0	1
RF2	Reserve	0	0	1	2	9	5	2	15
RF3	Reserve	1	3	4	3	2	5	4	6
RF4	Reserve	1	0	0	0	0	0	0	0
RF5	Reserve	1	0	0	0	0	1	1	4
RF6	Reserve	0	1	0	0	0	1	1	3
RF7	Reserve	NA	2	5	4	2	7	4	4
RF8	Reserve	NA	0	3	0	2	6	1	3
CF1	Control	0	4	1	1	4	6	7	7
CF2	Control	1	0	0	0	0	0	2	4
CF3	Control	0	0	4	5	4	3	18	9
CF4	Control	0	0	0	1	0	0	2	3
CF5	Control	2	1	10	5	1	3	4	2
CF6	Control	1	1	1	0	0	0	2	0
CF7	Control	NA	0	0	0	0	0	1	0
CF8	Control	NA	0	0	7	9	0	42	10

Sites (30+ cm blue cod)	Treatment	2006	2007	2008	2009	2010	2011	2012	2013
RF1	Reserve	0	0	1	0	1	0	0	0
RF2	Reserve	0	1	1	1	1	2	2	1
RF3	Reserve	0	1	1	1	1	1	2	0
RF4	Reserve	0	0	0	0	2	2	0	3
RF5	Reserve	0	0	0	1	2	2	1	0
RF6	Reserve	0	1	1	0	0	1	1	0
RF7	Reserve	NA	0	0	3	2	1	1	1
RF8	Reserve	NA	0	1	0	1	1	0	4
CF1	Control	0	1	0	0	1	2	1	0
CF2	Control	0	0	0	0	0	0	0	0
CF3	Control	0	0	0	0	0	1	0	0
CF4	Control	1	1	0	0	0	0	0	0
CF5	Control	0	0	0	0	0	0	0	0
CF6	Control	0	0	0	0	0	0	0	0
CF7	Control	NA	0	0	1	0	0	0	0
CF8	Control	NA	0	0	0	0	0	0	0